MATERIALS OF INDUSTRY

MATERIALS OF INDUSTRY

Their Distribution and Production

BY

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"Shop Problems in Mathematics"

WITH AN INTRODUCTION BY

ALBERT L. COLSTON

REVISED AND ENLARGED

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MATERIALS OF INDUSTRY

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VI

THE MAPLE PRESS COMPANY, YORK, PA.

Dedicated to the memory of

MY MOTHER
SUSAN MERSEREAU

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PREFACE

Frequent revision of a book of this nature is necessary because of changes constantly taking place in the industries it represents.

The main objectives of this revision have been to eliminate any matter that may have become obsolete, to add such related materials and processes as have developed since the former editions were published, and to bring others up to date where changes have taken place. It did not seem desirable to alter the general plan and arrangement of the topics as these are flexible enough to permit of being adapted to the needs of any ordinary local condition.

This book was originally written to meet a need felt in educational work for a more systematic study of the common materials of industry. It is intended for use not only in technical high schools but also in industrial and vocational schools and in other institutions where the study of these materials is taken up.

The selection and arrangement of the materials have their basis in the requirements of a course developed in the Brooklyn Technical High School over a period of several years. The immediate aim of the course is to give the students a working knowledge of the main facts of industry, including the distribution

and production of raw materials and their general properties, transportation, conversion into commercial products, and economic importance.

In arranging the subjects, two aims have been kept in mind: (1) to select and group together topics that present degrees of difficulty commensurate with the development of the student mind at the time they are being studied, (2) to make it convenient to study each subject at a time when it will best correlate with the work of other departments.

In the work at the Brooklyn Technical High School, it has been found that the subjects lend themselves admirably to the use of visual aids in teaching. Maps, charts, cuts, lantern slides, motion pictures, specimens, and models have been freely made use of with gratifying results. Many of these materials are available for free distribution by federal and state departments, leading industrial concerns, educational museums, and other agencies. As a rule the lecture method, sometimes employed in the use of such visual aids, is not encouraged. The students are trained to think for themselves and are required to do most of the talking in the classroom, the object being to develop powers of observation, logical methods of thinking, and clear expression as well as to acquire facts.

Notebook work has been found helpful, especially sketches of apparatus and outlines around which classroom discussions are carried on. Chemistry, physics, and mechanics are naturally touched upon and correlated, but no attempt to teach them as such

has been made. The course gives an excellent background for the study of these subjects.

A large percentage of the data used in compiling the book has been obtained from personal visits of observation to representative industries and from interviews with superintendents, foremen, and others intimately connected with them. Free use has been made of standard works of reference, current technical magazines, catalogues, and other trade literature.

In selecting the type of illustrations it was considered advisable to use line drawings in order that the student might focus his attention on the main features without the distracting presence of unimportant details often seen in photographs. Some of the drawings are original; the others have been obtained from various sources, due credit being given for them in the proper places.

In giving the definitions for the terms, it was considered advisable to confine their applications to the subjects in hand rather than to make them general. A brief explanation on the part of the teacher will clear up any confusion that may arise on this point.

Two types of questions have been used: the direct and the so-called "power" question—Group I and Group II, respectively, so arranged for convenience in teaching. The direct questions are naturally answered by definite statements in the text, but the answers to the power questions are intended to be formulated by the students from inferences and suggestions in the text and from everyday experiences in contact with the materials they are studying.

The author wishes to express his indebtedness to Dr. Albert L. Colston, principal of the Brooklyn Technical High School, for his encouragement, counsel, and suggestions in preparing the manuscript of the book.

He wishes to express his appreciation to his colleagues in the Department of Industrial Processes of the Brooklyn Technical High School, without whose splendid cooperation in developing the work the book would not have been possible.

He further wishes to acknowledge his gratitude to the following specialists in their respective fields for reviewing articles pertaining to their subjects: Ernest Johnson, assistant chief metallurgist, Republic Steel Corporation; Asher Atkinson, ceramist, Sayre and Fisher Brick Company; F. T. Harris, director of publicity, International Paper Co.; Frank W. Hess, assistant purchasing agent, F. A. Johnson, chief inspector, and Walter Niemyer, assistant mining engineer, Pennsylvania Coal Company; D. W. Yike, chief chemist, Great Lakes Portland Cement Company; Irving K. Cox, Allis-Chalmers Manufacturing Company, Inc., Crushing Cement and Mining Machinery Department; G. E. McGuire, export manager, The Carborundum Company; Herbert F. Prescott, secretary, New York State Conservation Department; W. G. Howard, New York State Superintendent of Forests; W. W. Weber, acting in charge of publication results, Federal Forest Products Laboratories; George D. Lain, superintendent, Reading Iron Company; Theodore M. Knappen, director of information, National Lumber Manufacturers Association; G. L.

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S. F. M.

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INTRODUCTION

Several years ago, when the Technical High School course for boys was organized in Brooklyn, it seemed desirable to introduce the study of materials and processes of industry in the first year of the technical course. Some such instruction had been given in a very fragmentary manner with certain shop subjects. While it added interest to these shop courses, it cut down the time available for the actual shop work to such an extent that we thought it wiser to give most of this information in a course running parallel to the shop work and closely related to it. By giving this subject separate consideration we were able to widen the field of inquiry in studying materials and processes not actually handled in the special shops and were also able to stress the need of scientific knowledge applied to industry. This in itself gives the normal boy a very good introduction to the study of science.

This particular school has a trying-out period during the first two years of the course. After this exploratory, and in a sense foundational, period is over, the boy is obliged to select a special course for the last two years. We feel that the subject here treated, combined with his other experiences in the various shops and drafting and recitation rooms, decidedly fits into our general scheme of practical vocational

guidance—that is, helping a boy to find himself by giving him a picture of the activities in the outside world of industry and, at the same time, encouraging him to try out many things for himself. Our graduates who have either gone out into the practical world or gone on to higher technical institutions uniformly testify that the instruction received in this subject has given them an excellent background and a better appreciation of the problems that confront them in industry or in college.

The author of the book, Mr. Samuel F. Mersereau, came to us as head of department within two years after the technical course was organized. He had had many years of practical experience in industry and in the teaching profession. There were no textbooks available for this work, and his fellow teachers were obliged to present their material for instruction in mimeographed form. The present text is, therefore, the result of several years of serious effort in the classroom, and I wish to compliment the author and the publishers in presenting "The Materials of Industry" in this attractive form.

ALBERT L. COLSTON,
Principal of the Brooklyn Technical High School.

SUGGESTIONS FOR TEACHERS

Materials of industry, as a separate subject, has been taught in different schools under such various names as Timber Science, Materials, Industrial Geography, and Industrial Processes. The educational soundness of this idea has been proved by the results that the author has obtained over a period of years. The work not only brings to the students a thorough working knowledge of the common materials used in industry but also offers a natural and excellent opportunity for cooperation with teachers of other subjects.

The conditions under which the work is given at Brooklyn Technical High School may offer suggestions for organizing the work in other schools.

The Department.—The department of industrial processes occupies eight special classrooms, one large lecture room, a preparation room, and a departmental office.

Classrooms.—Each classroom is equipped with a large demonstration table, hot and cold water, gas, electricity, vacuum and pressure, and also with a screen and darkening shades.

Lecture Room.—The lecture room seats 125 pupils. It is equipped with a unit demonstration table, a booth, thirty-five- and sixteen-millimeter sound

motion-picture machines, and facilities for the use of the stereopticon.

Lantern Slides.—The department has a special set of lantern slides for each of the subjects studied and several lanterns. A teacher desiring slides or other materials for individual classroom work can secure them on a moment's notice by sending to the preparation room.

Films.—Films can be borrowed or rented from museums, the Y.M.C.A., federal departments such as the U. S. Bureau of Mines and the U. S. Forest Service, state departments of education, and private firms; or the films can be purchased. Film or slide lessons are generally given once a week. On film or slide days the classes assemble in the lecture room, and their teachers accompany them and assist in the lesson. Motion pictures are used for study and not for entertainment. From time to time experts in technical fields accompany the films with talks on their respective subjects.

Other Teaching Aids.—In addition to films and slides, use is made of charts, of maps, and of drawings and models made largely by the pupils. Demonstrations are also performed before the classes. Coke making, the production of turpentine, wood distillation, wood preservation, electrolytic copper refining, oil refining, and the production of lime are among the processes demonstrated.

General Exhibit.—In the corridors opposite the classrooms are eight exhibition cases containing a large variety of specimens of materials for general

study. Each teacher also has a complete set of these materials for his use in individual classroom work.

Time.—The work is given five periods per week for one year. The course carries full credit and may be offered to meet the entrance requirements of colleges and higher technical institutions.

Of course, it is not necessary to have all the foregoing equipment on hand before introducing the work. A teacher can, with the cooperation of his pupils, soon collect sufficient equipment and materials to make the course both interesting and profitable. Not only is the work cultural but it also furnishes an excellent background for physics, chemistry, and mechanics as well as interesting and appropriate material for technical English themes.

The tentative weekly schedule of the subjects as taught at the Brooklyn Technical High School is as follows:

FIRST TERM

Week

1. Camps, cruising, and logging
2. Sawing lumber
3. Seasoning lumber
4. Wood preservation
5. Veneer and cooperage
6. Paper making
7. Review and test
8. Wood distillation and charcoal
9. Turpentine and rosin
10. Tanbark and leather
11. General forestry
12. Review and test
13. Petroleum and asphalt

14. Rubber and asbestos
15. Lime, cement, and concrete
16. Bricks, tiles, and terra cotta
17. Building stone
18. Review and final examination

Second Term

Week
1. Coal
2. Coke
3. Iron mining and transportation
4. Smelting iron ore
5. Bessemer steel
6. Open-hearth steel
7. Review and test
8. Rolling mills and forging
9. Wrought iron, cementation steel, and charcoal iron
10. Crucible steel and electric steel
11. Alloy steel, cast steel, cast iron, and malleable iron
12. Copper and aluminum
13. Review and test
14. Lead, zinc, tin, and non-ferrous alloys
15. Abrasives
16. Glass and plastics
17. Paint, varnish, and stain
18. Review and final examination

A typical outline of a week's work covering the work of the second week of the second term follows:

Coke

I. General uses
   - *A.* Industrial fuel (in metallurgy)
   - *B.* Domestic fuel
   - *C.* Reducing agent (smelting)

D. In manufacture of abrasives (silicon-carbide)
E. In synthetics

II. Coking coals (bituminous)
- *A.* Location of coking coal beds (in southwestern Pennsylvania, particularly)
- *B.* Grade of coal (low sulphur coal)
- *C.* Treatment before coking (pulverizing)

III. Coking processes
- *A.* Pit process (obsolete)
  1. Advantages
  2. Disadvantages
- *B.* Mitchell process
  1. Type and shape of oven
  2. Not used in this country
- *C.* Beehive process
  1. Ovens
     - *a.* Types (bank, single and double block)
     - *b.* General shape and size (dome, 12 feet in diameter, 7 feet high)
     - *c.* Parts (oven chamber, trunnel or eye, drawing door)
     - *d.* Construction (refractory lined mason work)
     - *e.* Location (near coking coal beds)
     - *f.* Advantages and disadvantages
     - *g.* Objections (waste of volatile matter)
  2. Charge and charging
     - *a.* Size (from 6½ to 8 tons)
     - *b.* Charging
  3. Time required (24, 48, or 72 hours)
  4. General character of coke (light, brittle, porous, nearly pure carbon)
- *D.* By-products process
  1. By-product oven
     - *a.* Shape (rectangular, long and narrow)

b. Size (from 30 to 40 feet long, from 6 to 15 feet high, from 12 to 22 inches wide)
c. Parts (oven, combustion chamber, hydraulic main, regenerative system)
d. Construction (reinforced, refractory masonwork)
e. Locations (near blast furnaces or cities)

2. Regenerative chambers
   a. Purpose and advantage (conserve heat, heat fuel and air)
   b. Construction (porous brick checkerwork)
   c. Location (below ovens)
   d. Operation (alternately heated with waste gas, heat fuel and air)
3. Charge and charging (pulverized coal)
   a. Size of charge (from 12 to 20 tons)
   b. Lorries
4. Coking process
   a. Time required (from 12 to 24 hours)
   b. Fuel used (gas)
   c. Discharging (pushed out with ram)
   d. Quenching (with water)
5. By-products
   a. Tar (base for dyes, creosote, etc.)
   b. Non-condensable gas (oven fuel, commercial)
   c. Ammonia sulphate (fertilizer)

MATERIALS OF INDUSTRY

CHAPTER I

FOREST PRODUCTS

LOGGING

Camps.—Logging camps are generally temporary quarters located in or near the forests to accommodate the lumberjacks and to house the animals, tools, and supplies necessary for carrying on logging operations. They vary in size and character according to the size

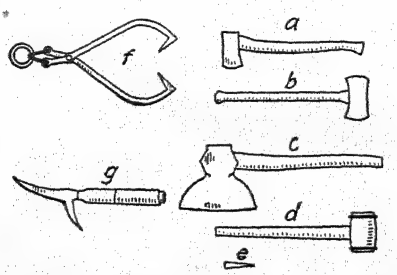

FIG. 1.—Logging tools. *a*. Single-bitted ax. *b*. Double-bitted ax. *c*. Broad ax. *d*. Beetle. *e*. Wedge. *f*. Skidding tongs. *g*. Pikepole.

of the job with which they are connected and the conditions under which logging must be done in different parts of the country. In large jobs a settlement may be established. Married men in some instances bring their families and live in regular houses constructed for their accommodation. Camps

of this character often have schools, churches, stores, a Y. M. C. A., a playhouse, a library, telephone, daily mail, electric lights, and even shower baths and, of course, radio sets.

For the average crew of fifty to sixty men in a typical temporary camp in the Northwest six or seven buildings are required. These generally consist of an office and store, a cook shanty, a mess hall, a bunk

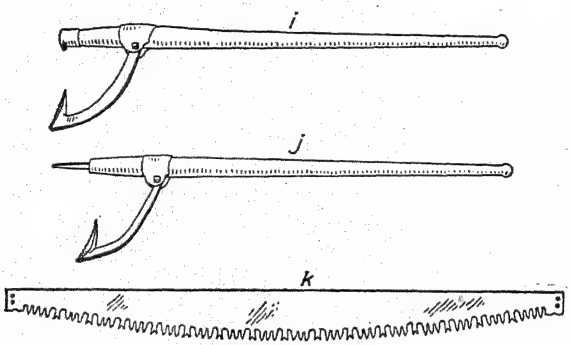

FIG. 2.—Logging tools. *i*. Cant hook. *j*. Peavy hook. *k*. Cross-cut saw.

house, a blacksmith's shop, a stable, and a storage cellar. For smaller jobs two or three medium-sized buildings are generally sufficient. Logging in the cypress swamps of the South often requires house-boats or floating camps. These are generally two-story affairs with the office, kitchen, and dining-room on the first floor and the sleeping quarters above. Special camps are also constructed on railroad cars and are moved from place to place as the logging progresses. Often logging camp cars are models of cleanliness and comfort. They are sometimes equip-

ped with electric lights, shower baths, hot and cold water, and even steam heat. In some instances after the timber has been exhausted, other industries are introduced, and old logging camps develop into thriving industrial cities. Bay City, Saginaw, Cheboygan, and Muskegon, Mich., are examples of such cases.

Formerly, temporary camp buildings were constructed of logs placed crib-fashion after the manner of the early pioneers' log cabins. But in recent years, unless the transportation of lumber into the forests is too expensive, they are sometimes constructed of rough lumber, covered with building paper. In nearly every case, however, they are either abandoned when no longer needed in a locality or dismantled and moved elsewhere.

Cutting Logs.—Once a camp is established, the actual work of log making begins. In some sections, especially when trees are small, the felling is done entirely by chopping; but this method is wasteful and leaves the butt log rough and uneven on the lower end. The more common method of felling is by supplementary sawing with a two-man cross-cut saw. A V-shaped notch, sometimes called the "undercut," is chopped on the side of the tree in the direction in which the fall is to take place (Fig. 3). This is done to prevent the butt from slabbing or splitting off and damaging some of the lumber and to aid in felling the tree in the desired direction. The saw is started opposite to and just above this notch and worked horizontally. A wedge is driven into the kerf to prevent the saw from binding and to aid in forcing the tree over in

the desired direction. The work is dangerous, and the workmen must be on the alert to avoid accidents. Skill is also required to prevent the trees from lodging against other trees or damaging their trunks by hitting rocks or other obstructions and also to land them in such positions that the logs can be cut and removed with the minimum amount of labor. There is a temptation to leave stumps high because the trunks are smaller and easier to cut above their natural flare near the ground, but this practice is wasteful and is not allowed in the best managed jobs. Machine tree-felling saws have been introduced, but as a rule have not been extensively used.

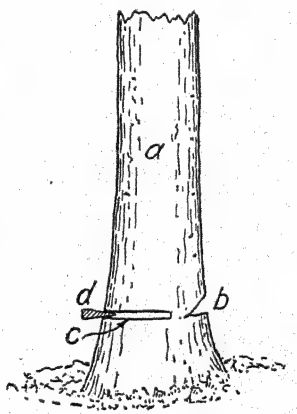

FIG. 3.—Tree felling. *a.* Tree trunk. *b.* V notch. *c.* Saw kerf. *d.* Wedge.

After the trees are felled, "limbers" free the trunks from branches with axes as far up into the tops as they are suitable for commercial logs. The trunks are then sawed into standard lengths by the log buckers, or, if the job is large and handling machinery is used extensively, they are transported to the mills in long sections and resawed to standard lengths by machinery. In sections of the country where the trees are about two feet and less in diameter, the two-man cross-cut saw is generally used for cutting the trunk into logs. Where they are larger, especially in the case of the large firs and redwoods in the Northwest, they are cut with a

one-man saw made extra heavy and long for the purpose.

Log Transportation.—The next step in the process is to secure the logs from the forest and transport them directly to the mills or to the points where they are yarded for further shipment. Before this can be done, logging roads and rollways must be cleared. Often corduroy roads must be constructed over marshy places, and chutes, tramways, and railroads built

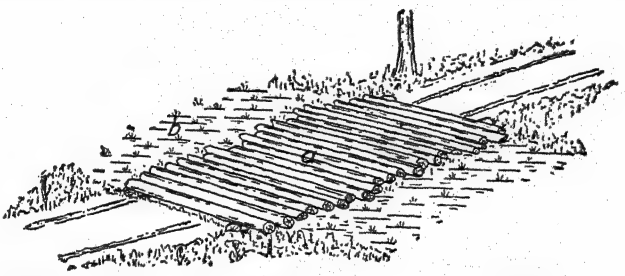

FIG. 4.—Corduroy road. *a*. Small logs or poles. *b*. Marshy land.

(Fig. 4). In the smaller jobs where the logs are not large and the nature of the ground will permit, the skidding is done with draught animals, but in the larger jobs, especially where logging railroads are used, it is done by machinery. A common practice in large jobs is to leave a spar tree, or mast, which is securely guyed from the top to surrounding stumps (Fig. 5). To the top of this mast is attached a block through which plays a cable that reaches out a long distance in all directions. (Even steel spars are sometimes used when the size of the job and other conditions warrant going to such expense.) Electric motors, gasoline, or donkey engines operate the cables on drums and haul

the logs to the foot of the mast where they are loaded on to cars. Another method of skidding is by a cableway skidder (Fig. 6). This consists of a heavy

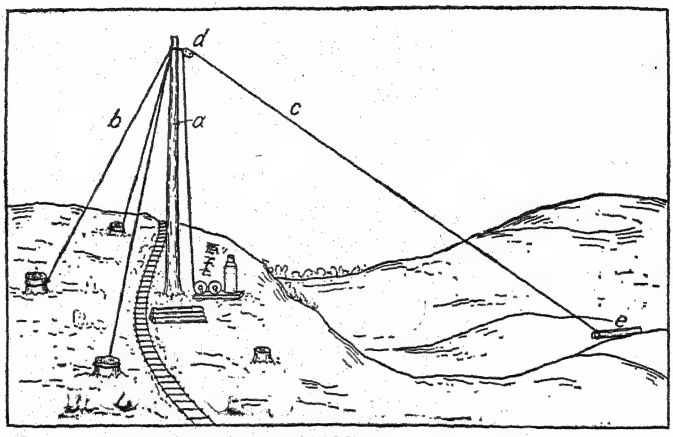

FIG. 5.—Single spar-tree log skidding. *a.* Spar tree. *b.* Guy rope. *c.* Traction rope. *d.* Pulley. *e.* Log. *f.* Engine. (*Redrawn from "Lumber" by Bryant, courtesy of John Wiley & Sons, Inc.*)

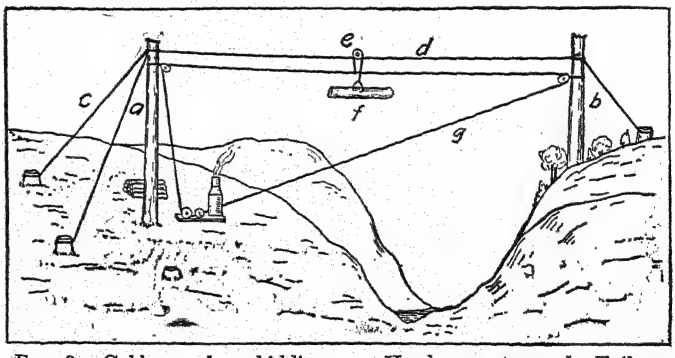

FIG. 6.—Cableway log skidding. *a.* Head spar tree. *b.* Tail spar tree. *c.* Guy rope. *d.* Cable. *e.* Carrier. *f.* Log. *g.* Traction rope. (*Redrawn from "Lumber" by Bryant, courtesy of John Wiley & Sons, Inc.*)

cable stretched from a head spar to a distant tail spar over the section where the logs lie. A trolley or skidding carriage plays back and forth on this cable and

brings the logs in. This method is especially useful where logs must be skidded over deep gorges, through swamps, or in steep and rocky places.

Skidders supplied with adjustable derricks are sometimes constructed on railroad cars and moved forward as the work of logging advances. They are also mounted on runners and in some instances have caterpillar tractor mechanism and move about by their own

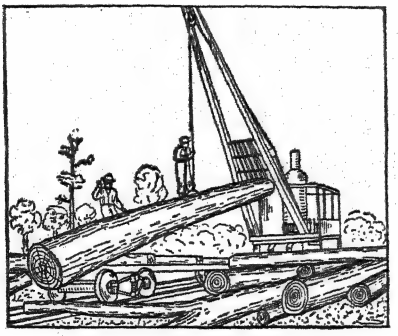

FIG. 7.—Steam log loader.

power. A typical spar skidder reaches out about a quarter of a mile in all directions and therefore works over an area about half a mile wide. Some skidders are equipped with loading devices and load the logs on to the cars as well as bring them in.

In smaller jobs logs are transported to local mills or shipping points by draught animals. In the North, when possible, this is done in winter on low bob sleighs, because of the ease with which the logs can be loaded and larger loads hauled. In cold weather the roads are sometimes flooded to make them icy. In many sections of the country, especially in the South where

sleighs cannot be used, special trucks and wagons take their place. Sometimes these trucks are high two-wheeled affairs so constructed that the logs can be carried slung from underneath their axles (Fig. 8).

The cheapest method of transporting logs to distant mills is by floating or driving them in a stream. This is generally resorted to when conditions are favorable. As a rule, the logs are hauled to the rollways on the

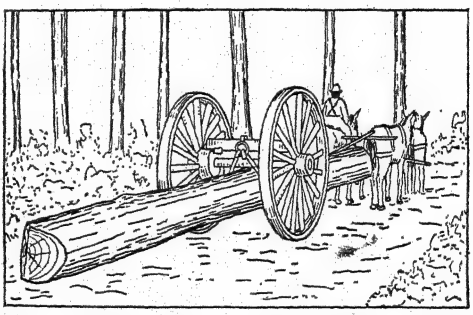

FIG. 8.—High two-wheel truck for hauling logs. (*Courtesy of U. S. Forestry Service.*)

banks in winter and there await the spring floods to carry them down to their destination. Log driving is one of the most interesting and exciting activities of logging operations. The drivers become very expert in moving about on the floating masses and often perform feats of daring that would make the hair of the ordinary land man stand on end. They even have rough sports on the floating logs that require mental alertness and a high degree of skill. Jams must be loosened either by hand or by the aid of dynamite, and the logs must be kept from stranding in shallow water. When they reach their destination,

they are stopped by booms, which may be simple chains of logs stretched across the surface of the stream or permanent structures of concrete and timbers. In navigable streams the booms must be so constructed as to open up and allow the passage of boats. Frequently when streams are normally too small to float logs, splash dams are constructed which impound sufficient water to create a temporary flood for the

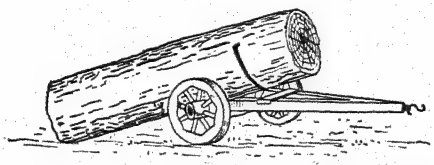

FIG. 9.—Low two-wheel truck for hauling logs.

purpose. (Since the advent of gasoline trucks for log transportation, log driving is relatively not so important.) Log rafts are also used where conditions warrant their construction and where towing is necessary. A striking example of this can be seen in the cigar-shaped rafts of the Northwest.

In the last three or four decades, however, as lumbering has become more an industry of the South and far West, the logging railroad has generally superseded navigation as a means of transporting logs to the mills. In some cases these logging railways are permanent and also act as common carriers; but the great bulk of the mileage is temporary, and the rails are taken up and shifted from time to time to meet the requirements of the operations. Steam is usually the motive power on these railways, and the engines are especially built to negotiate sharp curves and for steep grades. In some instances electric locomotives are used.

In recent years tractors, usually of the caterpillar type, have come into wide use, especially in the West and South, for primary transportation of the logs, that is, from where they are felled to the place where they are assembled for distant transportation, which is usually a point on a logging railway.

An interesting method of transporting logs in mountainous country is by log slides or chutes. These are rough troughlike affairs, generally constructed of trunks of trees placed side by side down steep inclines. They are sometimes greased in summer and iced in winter to make them slippery. As a rule, they terminate at ponds or rivers so that the logs will float out of the way as soon as they leave the chute. Tramways (small railroads, often with wooden rails) are sometimes used when the nature of the country and the character of the job will permit; and in larger jobs standard railroads are constructed and advanced as the logging progresses. Often a high degree of engineering skill is required in constructing logging railroads, for deep gorges must be trestled, sharp curves negotiated, steep grades overcome, and other problems solved that are seldom met with in ordinary railroad construction. Many logging railroads pass through sections where they are later needed for general transportation, and they eventually become parts of regular railroad systems. Gasoline trucks are rapidly coming into use for log transportation, not only for short hauling but also as a substitute for logging railroads and river driving. They often go about in the forests and pick up logs. Caterpillar tractors are also finding increased favor for

skidding, yarding, and hauling with the result that highline or cableway logging is on the wane.

In a few instances flumes are used for log transportation, but their use as a rule is confined to floating paper bolts, railroad ties, mine props, and lumber after it is sawed (Fig. 10). At one time a flume seven miles long was used in the Adirondack Mountains to transport paper bolts down to the Ausable River.

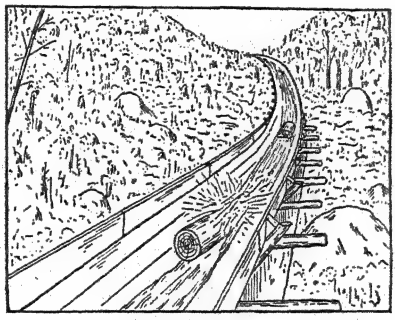

FIG. 10.—Flume.

Some lumber companies use flumes to transport lumber when their mills are located a distance from the regular shipping points. One flume of this nature was reported to be forty miles long and had a carrying capacity of about 40,000,000 board feet of lumber per year. It required about seven hours for a piece of lumber to make the journey in this flume.

Logging Terms

boom—A chain of logs or some other construction to corral logs in a river or pond.

butt log—The log from the bottom end of the tree trunk or the one nearest the stump.

cant hook—A short, strong, wooden lever with a swivel hook in one side near one end for rolling logs.

chopper—One who wields the ax in the woods.

cookee—A logging-camp cook's helper.

corduroy road.—A temporary road over marshy places constructed of stringers placed lengthwise, covered with a floor of poles placed at right angles to the stringers.

cruise—A trip of inspection through the woods with the idea of determining the amount of lumber in the standing trees.

drive—A lot of logs floating in a stream or pond.

feller—One who fells the trees in logging.

gunstick—Scissors-like poles used to determine the direction of the fall of a large tree.

log bucker—One who cuts the trunks of trees into standard-length logs.

log chute—A rough troughlike slide constructed of trunks of trees down a steep slope for sending down logs.

logger—One who works at producing logs.

log scale (log rule)—A special ruler with graduations that show the number of board feet in a log.

lumber—Any standard salable wood sawed or split to size.

lumberjack—A man engaged in the lumber woods to cut logs. Also a log driver.

lumbermen—Men working in the lumber woods or engaged in the lumber business.

lumber scale—A special ruler graduated so as to show the board feet in a piece of lumber.

paper bolts—Short logs, three or four feet long, a convenient length for handling, used for paper pulp.

peavy hook—Same as cant hook except that it has a steel spike at the lower end for pushing logs in a drive.

rivermen—Men engaged in driving logs in a river or other body of water.

rollway—An open space by the roadside, on the river bank, or elsewhere where logs are temporarily stored.

scaler—One who measures the board feet in logs.

skidder—One who skids logs. Also a skidding machine.

skidding—Dragging logs along the ground from where they fall to the rollways or cars.

slashing—The tops, branches, etc., left behind after the logs have been removed.

splash dam—A temporary dam for impounding the water to create a temporary flood to float logs.

springboard—A short strong board with a hook attachment at the end for driving into a tree to support the workmen when felling.

swamper or limber—One who trims the branches from the trunks of the trees after they are felled.

tramway—A temporary railroad used for lodging, sometimes constructed with wooden rails.

windfall—A lot of trees blown down by the wind.

yarding—Collecting logs in a mill yard.

Logging Questions

Group I

1. Name two types of camps.

2. What becomes of lumber camps after the logging operations are finished?

3. Name two methods of felling trees.

4. Give two reasons for making the undercut in felling. On which side of the tree is this made?

5. What are some of the common lengths of logs?

6. Explain when draught animals could be used for skidding and when machinery should be used.

7. Under what conditions should splash dams be used?

8. Why should log chutes terminate in a stream or pond of water?

9. Name ten hardwoods and ten softwoods used for lumber (see page 132).

Group II

10. Why is logging healthful work?

11. Why are cruises generally necessary before establishing a logging camp?

12. Name important points to consider in establishing a logging camp.

13. Name special advantages of logging camps on railroad cars over stationary camps.

14. How can waste be avoided in felling?

15. How can waste be avoided in cutting trunks into standard lengths?

16. How far toward the top should a tree trunk generally be used for logs?

17. Why is wood near the stump of the tree generally harder and stronger than that farther up?

18. Why is the wood of a tree grown in the open generally stronger and harder than that grown in the forest?

19. Who is the owner of navigable streams and ponds?

20. Who has a right to drive logs in a river?

21. When two parties drive logs at the same time, how are the logs of each identified?

22. Why are logs generally driven in the spring of the year?

23. What must be the nature of the country to permit of the use of log chutes?

24. Why is the two-spar practice better for rough country than the single spar?

25. Why are flumes generally unsuitable for transporting large logs?

26. What particular advantage have flumes in transporting lumber, paper bolts, etc.?

27. How is water supplied to flumes?

28. Mention several damages that might result from careless felling.

29. Explain why log driving is generally the cheapest form of log transportation.

30. Why does the breaking of a boom in a river result in great loss?

Summary

1. Logging camps are generally temporary quarters for housing the lumbermen and for suitable accommodations for shelter and care of logging equipment.

2. Sometimes logging camps develop into permanent industrial towns and cities, *e.g.*, Bay City, Saginaw, Cheboygan, and Muskegon, Mich.

3. A typical logging crew generally consists of fellers, limbers, and log buckers.

4. Felling is done with axes and cross-cut saws, by hand (sometimes felling machines are used). Other hand logging tools are the cant hook, peavy hook, and measuring rod. The wedge and beetle are used to keep the saw from binding and to force the tree over in the desired direction.

5. Often much good lumber is wasted by leaving high stumps and large tops.

6. Felling is particular work and must be done with care to avoid accident and injury to the forests or to the lumber in the tree.

7. Standard lengths for logs are 8, 10, 12, 14, 16, 18 feet, etc.

8. Logs are skidded to rollways, railroad cars, or banks of streams by draught animals. Special skidding machines including single-spar tree skidders and cableway skidders are also used with logging railroads. Chutes are used when the nature of the country permits. Flumes are also used, but more especially for smaller pieces, as paper bolts, mine ties, and pieces of lumber after it is sawed.

9. Log driving is a cheap and efficient means of log transportation and is generally used when conditions permit.

10. Booms are constructed across streams or in ponds to stop and hold the logs together at their destinations.

SAWING LUMBER

Before cutting the logs into lumber it is well to learn something of the general structure of trees in order better to understand why certain methods of sawing are adopted.

Classes of Trees.—Trees in general may be classified in three different ways: (1) endogens and exogens, (2) deciduous and evergreen, (3) softwoods and hardwoods. They are also known by the botanical names of "angiosperms" (deciduous trees) and "gymnosperms" (evergreens). Endogenous trees, or inward growers, are found principally in the tropics, palm trees being representative of this type. Their wood does not have a ring structure like that of exogenous trees but grows in a sort of fibrous, uniform mass (Fig. 11). It has little practical value for construction, except in fishing rods, canes, and a few other minor fancy articles. Exogenous trees, or outward growers, grow a new layer or ring of wood, called the "annual ring," each year (Fig. 13). A new layer of inner bark

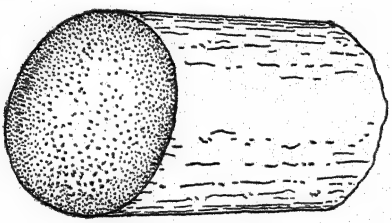

FIG. 11.—Cross-section of endogenous tree trunk.

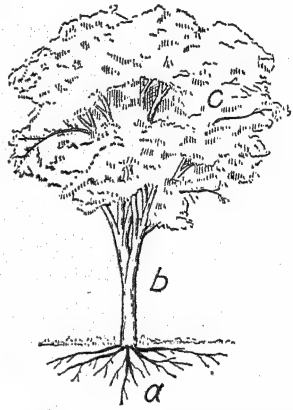

FIG. 12.—General parts of a tree. *a*. Roots. *b*. Trunk, body, or bole. *c*. Crown.

is also formed at the same time. From this class of trees all lumber used in general construction is obtained. Deciduous trees are trees that shed their leaves in the fall and remain bare all winter. As a rule, they are the broad-leaved hardwoods, as oak, beech, birch, maple, hickory, sycamore, elm, gumwood walnut, and others. Evergreen trees are those with needle-like leaves, as the pines, hemlocks, spruces,

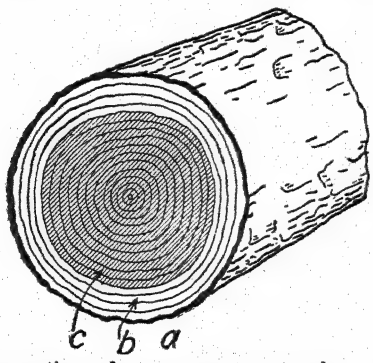

FIG. 13.—Cross-section of exogenous tree trunk. *a*. Bark. *b*. Sapwood. *c*. Heartwood. There are two kinds of bark. The outer bark protects the tree from injuries. The inner bark carries prepared food from the leaves to the cambium layer. The sapwood carries sap from the roots to the leaves. The heartwood, which is inactive, gives strength to the tree.

balsam, fir, the cedars with leaves resembling delicate lace, and the live oak of the Southern states. The evergreen trees do not shed their old leaves until the new ones have grown on; hence, they always have a green appearance and are called "evergreens." As a rule, in the North they are the softwoods. (In some instances, this classification is misleading. Basswood, poplar, whitewood, aspen, and cottonwood are classified as hardwoods, but, in reality, they are among

the softer woods, whereas long-leaf pine and yew are classified as softwoods and are among the harder woods.)

General Parts of Trees.—Again every individual tree is divided into three general parts: the roots, the trunk, body, or bole, and the crown comprising the branches and foliage (Fig. 12). The roots hold the tree in position and collect nourishment from

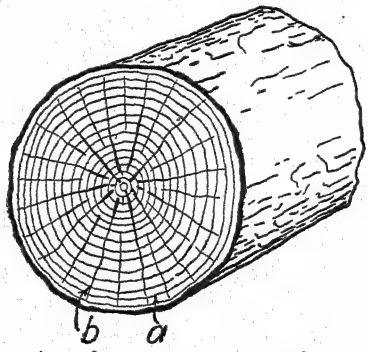

FIG. 14.—Cross-section of exogenous tree trunk. *a*. Annual rings. *b*. Medullary rays.

the soil, the trunk supports and conveys sap to the crown, and the crown shades the roots, collects nourishment from the air, and bears seeds for reproduction. A tree growing in the open is generally short and has a large bushy crown because of the abundance of sunlight it receives on all sides, while one growing in the forest is tall with a slim high crown because of its struggle to reach upward for the sunlight. Here is seen the same principle that causes a house plant to bend outward toward the light when placed in a window. Again, the trunks of trees are divided into heartwood, sapwood, and bark (Fig. 13) and an inner

thin layer between the bark and wood, known as the "cambium" layer, in which new wood and bark are formed. This part has no practical value for lumber.

Structure of Tree Trunks.—As has been suggested, a cross-section of an exogenous tree trunk will show

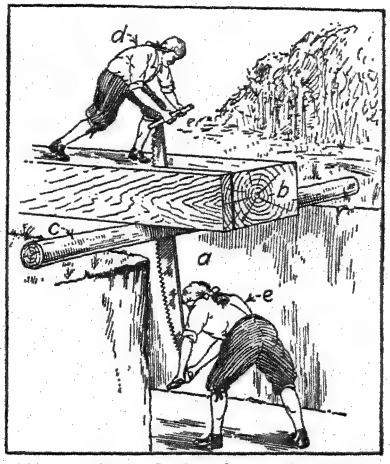

FIG. 15.—Pit sawing. *a.* Pit. *b.* Flitch. *c.* Support. *d.* Head sawyer. *e.* Tail sawyer or pit man.

a series of concentric rings varying in thickness and somewhat irregular in form according to conditions under which the tree has grown. The age of the tree can be determined by counting the rings, and it is also possible to learn something of the history of the seasons from them. If a ring is wide, it indicates that it was formed in a wet, good growing season; if it is narrow, the season was probably the reverse. It is possible to have two rings for the same year provided the tree starts growing and then stops for a time and afterwards continues to grow for the remain-

der of the season. In such instances, however, the rings are generally very thin and can easily be distinguished from those grown in the regular time.

In addition to rings, thin lines can be seen in the section radiating outward from the center or pith simi-

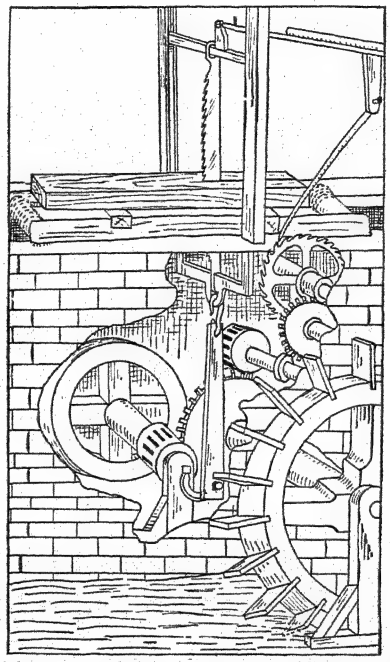

FIG. 16.—Primitive up-and-down sawmill. (*Courtesy of Standard Oil Company of New York.*)

lar to the spokes of a wheel. These are known as "medullary rays" (Fig. 14). They are present in all kinds of exogenous trees but are more conspicuous in some woods than in others. In the oaks both rings and rays show up clearly. In chestnut and ash only the rings show prominently; and in sycamore

the rays show clearly, but the rings can scarcely be seen at all. On account of the presence of large medullary rays in the oaks we are able to secure the beautiful silver grain seen in quartered-oak furniture and other fine oak woodwork.

Development of Lumber Sawing.—In early times lumber was sawed by hand and is even now, to some extent, in some foreign countries. The first method employed in our own country was known as "whip"

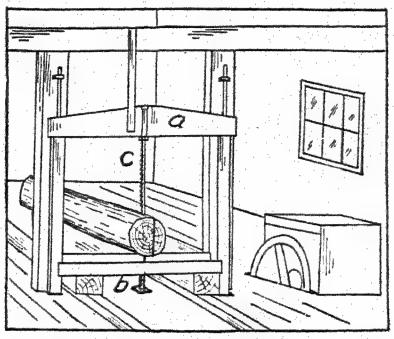

FIG. 17.—Up-and-down sawmill. *a.* Frame, or gate. *b.* Carriage. *c.* Saw.

or "pit" sawing (Fig. 15). The former name was applied because the saw was thin and whiplike, similar to a two-man cross-cut saw, and the latter name because the logs, when too large to be propped up, were suspended over a pit in which one man worked. The head sawyer stood on the top of the log and pulled the saw upward, while the tail sawyer, or pitman, worked underneath and pulled it downward when it did its cutting. The work was slow and laborious, and the pieces uneven, but enough lumber was turned out to supply the limited needs of the early pioneers and to

export considerable quantities to England, Holland, and elsewhere.

The up-and-down saw, sometimes called the "gate" or "frame" saw, because it was adjusted in a framelike

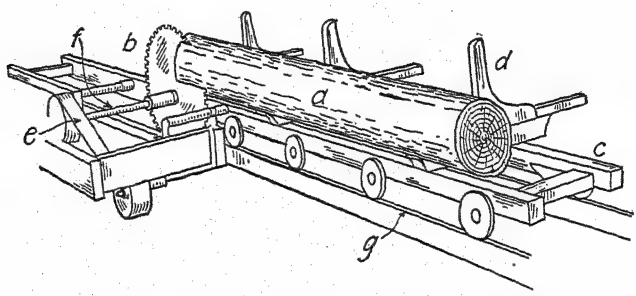

FIG. 18.—Circular sawmill. *a*. Log. *b*. Saw. *c*. Carriage. *d*. Head block. *e*. Driving belt. *f*. Saw arbor. *g*. Track.

structure, was the first power saw to be used in the country; and the source of power was either the overshot or the undershot water wheel (Fig. 17). Until about 1870 this type of saw was practically the only one used in lumber manufacture, and many evidences of its use can still be seen on lumber in older buildings in the eastern sections of the country. A modified type of the up-and-down saw was known as the "muley" saw. It was thick and stiff enough to stand up without the aid of a frame but was supported by guides adjusted above and below the log. The up-and-down frame saw has its counter-

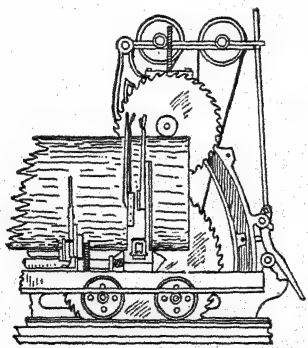

FIG. 19.—Double circular sawmill. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

part in modern mills in the reciprocating gang saw (Fig. 23).

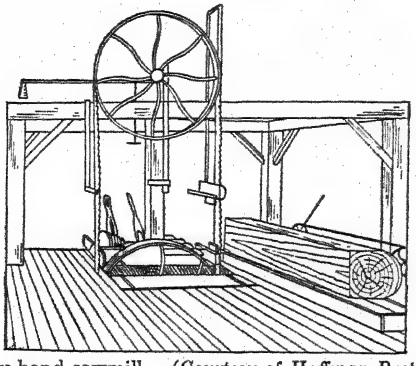

FIG. 20.—Early band sawmill. (*Courtesy of Hoffman Brothers Company.*)

The next step in advance in lumber sawing was brought about in 1870 by the advent of the circular

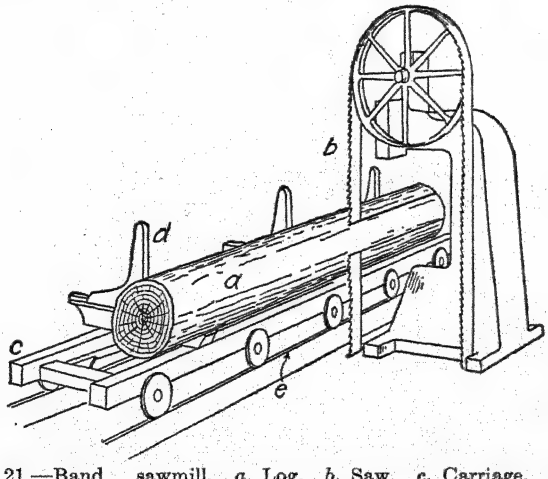

FIG. 21.—Band sawmill. *a.* Log. *b.* Saw. *c.* Carriage. *d.* Head block. *e.* Track.

saw (Fig. 18). Because of the cheapness of this saw and the ease and speed with which it operates it revo-

lutionized the whole lumber industry. A glance at the relative cutting speed of the two types of saws will clearly show why this is true. The rim, or cutting, speed of a 4-foot circular saw is generally about 10,000 feet per minute, while that of the best up-and-

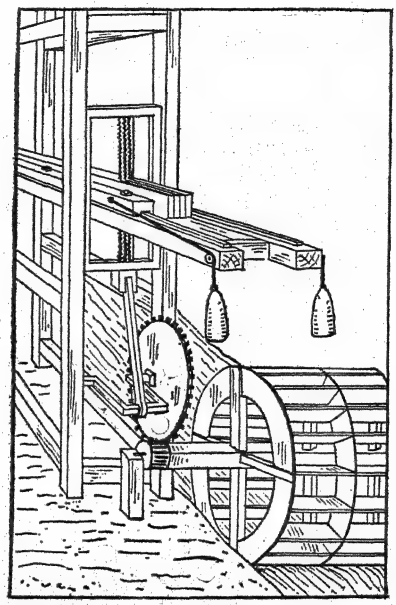

FIG. 22.—Early gang sawmill. (*Courtesy of Standard Oil Company of New York.*)

down saw was only about 300 or 400 feet per minute. Since about 1890, circular saws have in turn been displaced by band saws, especially in the larger mills (Fig. 21). They are still holding their own, however, in portable and other small mills, where the logs are small and the jobs not large enough to warrant the expense of installing band saws. They are also used on gang resaws, edgers, slashers, lath mills, shingle

mills, etc., in large plants using band saws for head, or main, saws.

Band saws range in size from those less than ¼ inch in width used in ordinary woodworking plants to those 18 inches or more used for large timber of the Northwest. They are made in two types, single cutting and double cutting, or those with teeth on one edge and those with teeth on both edges, respectively.

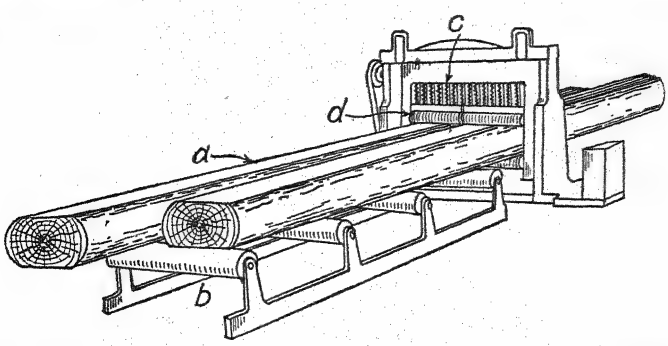

FIG. 23.—Modern gang sawmill. *a.* Flitches. *b.* Rollers. *c.* Saws. *d.* Feed rolls.

The single-edged saw cuts lumber with the carriage passing in the forward direction only, but the double-edged saws cuts with the movement in either direction.

Theoretically the double-cutting saw should be twice as efficient as a single cutting, but this is not the case, because the extra trouble of handling the lumber and the time consumed by the slower movement of the return journey of the carriage, as well as the greater precautions required to keep the saw adjusted and in order, practically offset any advantage gained by the double-cutting action. As a rule, the larger mills are also supplied with reciprocating (up-and-down) gang

saws (Fig. 23). These machines consist of a series of straight, vertical saws adjusted parallel with each

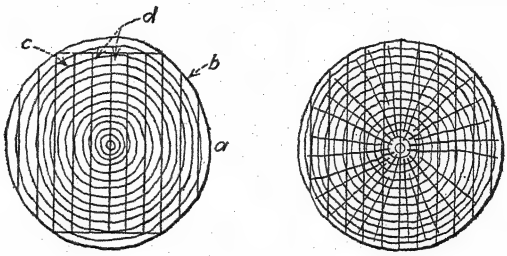

FIG. 24.—Methods of common, or slash, sawing of lumber. *a.* Slab. *b.* Edging board. *c.* Stock boards. *d.* Quarter-sawed effect.

other in an upright frame and spaced equidistantly apart, according to the thickness of the lumber desired

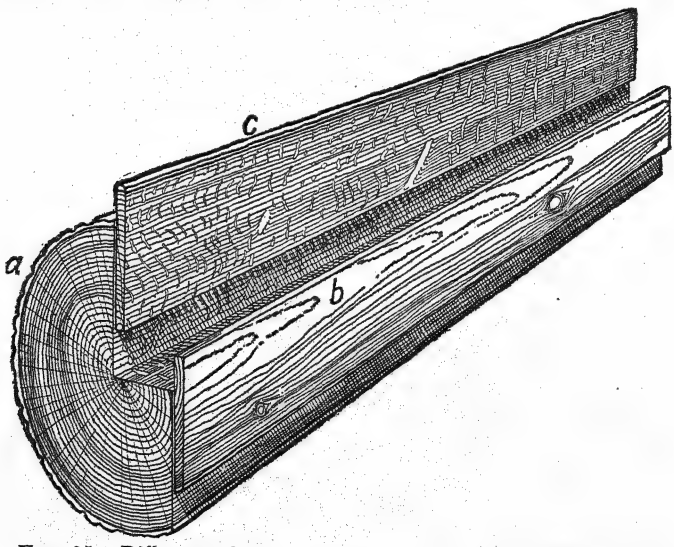

FIG. 25.—Difference between common and quarter-sawed lumber. *a.* Log. *b.* Common sawed board. *c.* Quarter-sawed board. (*Courtesy of U. S. Forestry Service.*)

(generally one inch). The logs are first slabbed on two opposite sides on the head saw and then sent through

the gang saw to be cut into boards. Edging boards go through edgers which square them up, and the slabs are resawed on special mills into mason laths, box lumber, pickets, etc. In some mills the better grades of odds and ends are worked up into shingles, but the slabs as a rule are not suitable for the purpose because of their large percentage of sapwood.

Methods of Sawing.—There are two general methods of sawing lumber: common, or slash, sawing; and quarter, or edge-grain, sawing. In common sawing the object is to make as much lumber from the log as possible without regard to the figure or appearance of the grain. There are several methods of turning the log to accomplish this, some of them illustrated in Fig. 24. In quarter sawing the aim is not only to cut the log with a minimum amount of waste but also to bring out certain artistic grain effects or to produce vertical or edge-grain lumber of special quality. Formerly the logs were first quartered (hence the name), and then each quarter sawed as a unit to the best advantage (Figs. 25, 26, 27). But in recent years several other methods have been devised. In every case the aim is to saw the log in such a manner that the line of the annual

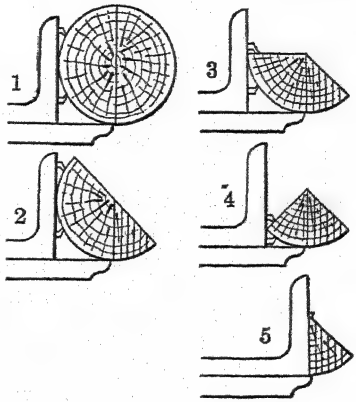

FIG. 26.—Modern method of quarter sawing. (*Courtesy of U. S. Forestry Service.*)

rings will run as nearly as possible directly across the thickness dimension of the boards, and the medullary rays will be parallel with the width dimension, which brings out certain grain effects. This means that the boards must be sawed radially from the center of the log as far as possible. Figure 26 illustrates a common method of quarter sawing. Quarter-sawed lumber not only presents a more artistic appearance than common-sawed lumber but does not warp so badly in seasoning or sliver so much when given hard usage.

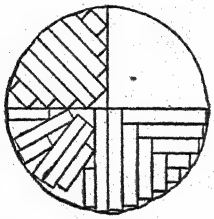

FIG. 27.—Quarter sawing. Three methods.

The equipment and operation of a large modern sawmill are often examples of special efficiency. (Some of the largest mills have a capacity of one million board feet per day.) In most large mills several types of saws can be seen in operation, each one doing its particular bit to convert the logs into useful lumber. The machines are so located that the pieces pass naturally from one machine to the next without loss of time. Logs are brought in and placed and turned on the carriage by machinery; the lumber is shunted away on live rolls, and the boards are edged and slashed and even sorted to length without the touch of human hands. Even the sawdust and other mill refuse are carried away by mechanical conveyors to the engine room to be fed by gravity into the furnaces or to the refuse burners to be consumed by a perpetual fire that needs very little attention. Besides sawmills, there are sometimes planing mills, box

factories, door and window factories, and pulp and paper mills, all part of the same organization.

In recent years, however, there has been a tendency to return to the use of smaller sawmills, especially portable mills. This is largely due to the fact that our onetime extensive original forests are becoming scarcer and that much of the lumber now cut comes from second-growth trees with a yield per acre that will not warrant the expense of the installation of a large plant.

Classes and Sizes of Lumber.—All lumber is designated either as standard stock or as special bill lumber. Standard stock includes all sizes that are universally used in house and other common construction, as one-inch boards, two by fours, two by sixes, two by eights, four by sixes, etc., of standard lengths. Bill lumber includes all pieces cut to special dimensions for some definite purpose, as extra-long dock timbers, members for trestle work, timber for bridges, for freight cars, and the like.

As a rule, lumber less than 1½ inches thick is designated as "boards"; from 1½ to 4½ inches, as "planks"; and over 4½ inches as "timber." In calculating board feet, 1 inch in thickness is taken as the standard. Everything less than 1 inch is calculated as 1 inch. Intermediate thicknesses, as 1½ inches, are calculated on the basis of the actual thickness.

The following table shows rough sizes of southern pine adopted by a large lumber association. In recent years most of the smaller sizes of frame lumber have

been dressed (planed) before being put on the market; consequently, the thickness and width dimensions run from ⅛ to ¼ inch smaller than the rough dimensions.

1 × 4 in. × 8 to 16 ft.	3 × 6 in. × 8 to 16 ft.
1 × 6 in. × 8 to 16 ft.	3 × 8 in. × 8 to 16 ft.
1 × 8 in. × 8 to 16 ft.	3 × 10 in. × 8 to 16 ft.
1 × 10 in. × 8 to 16 ft.	3 × 12 in. × 8 to 16 ft.
1 × 12 in. × 8 to 16 ft.	4 × 4 in. × 8 to 16 ft.
2 × 4 in. × 8 to 16 ft.	6 × 6 in. × 8 to 16 ft.
2 × 6 in. × 8 to 16 ft.	8 × 8 in. × 8 to 16 ft.
2 × 10 in. × 8 to 16 ft.	10 × 10 in. × 8 to 16 ft.
2 × 12 in. × 8 to 16 ft.	12 × 12 in. × 8 to 16 ft.
3 × 4 in. × 8 to 16 ft.	14 × 16 in. × 8 to 16 ft.

Sawing Terms

angiosperms—Trees that shed their leaves in the fall.

annual rings—Yearly layers of wood added to the outward growth of exogenous trees.

band saw—An endless belt of thin steel with teeth on one or both edges.

board foot—The unit of measure for ordinary lumber: 1 by 12 by 12 inches.

carriage—The car that brings the logs to the saw.

centrifugal force—The force that tends to pull outward from the center in a rapidly revolving object.

circular saw—A thin disk of steel with teeth in its rim.

cross-grain—At right angles, or oblique, to the direction of the fibers in the wood.

cup shake—Splits that follow the curve of the annual rings.

deciduous trees—Same as angiosperms.

edging—A narrow strip from the edge of a board not filled out, or the strip sawed off the edge to make the board square.

edging board—A board generally cut next after the slab with its edges not filled out.

end grain—The surface of wood cut across the ends of the fibers.

evergreen trees—Trees that do not shed their leaves in the fall, but remain green all winter, generally the needle-leaved trees.

gang saw—A machine equipped with several saws for cutting a number of pieces at one operation.

gymnosperms—Same as evergreen trees.

medullary rays—Apparent thin lines radiating outward from the pith of the section of a tree trunk resembling the spokes of a wheel, in reality the ends of thin sheets of wood.

mill refuse—Slabs, sawdust, edgings, and other pieces about a sawmill not good for lumber.

mill run—All unsorted lumber as it comes from the saw.

planks—Common run of lumber 1½ inches or over and generally 4½ inches or less in thickness.

quarter sawing—To saw lumber, formerly by quartering the log, to secure certain grain effects, especially in oak to make the medullary rays show figure.

scantling—Smaller pieces of lumber nearly square, as two by fours, three by fours, four by fours, etc.

slab—The first cut taken from the log in sawing.

slash sawing—To saw lumber through and through without regard to the grain effect, to obtain the most lumber possible.

slasher—Special small circular saws in a large mill for cutting boards to length.

star shake—Splits in wood that follow the line of the medullary rays.

straight grain—Pieces of wood with the sides running parallel with the fibers. Wood that will split straight.

timber—(1) A stand of merchantable trees. (2) Large, nearly square pieces of lumber. (3) The quality of wood.

up-and-down saw—A flat straight saw which works up and down, generally in a frame. (See Gang saw.)

wane—The natural beveled edge of a board cut to the surface of a log. A board not filled out on the edge.

wind shake—A split in lumber caused by the wind shaking the tree before it is felled.

Tree-structure and Sawing Questions

Group I

1. Name the general parts of a tree, and give the purpose of each.

2. How and why does a tree grown in the open differ from one grown in the forest?

3. How can we determine the age of a tree from a cross-section of its trunk?

4. How can we read history from the cross-section of a tree trunk?

5. Name kinds of wood in which the annual rings are prominent.

6. Give reasons why oak is especially desirable for interior finish and furniture.

7. Where did the names "whip" and "pit" saw originate?

8. What is the general range of size in band saws?

9. What is meant by "standard" lumber; "bill" lumber?

Group II

10. What condition on a tree trunk causes a knot in lumber?

11. Explain why sawing lumber was among the first industries to develop in this country.

12. Why is wood around a knot generally harder than elsewhere?

13. Why were gristmills often operated in connection with early sawmills?

14. How did the whip saw differ from the modern two-man cross-cut saw?

15. In sawing 1-inch board, what percentage of the wood is wasted in sawdust if the saw kerf is $\frac{1}{4}$ inch thick?

16. How can we determine whether or not a board is quarter sawed?

17. Why is sapwood generally inferior for lumber to heartwood?

18. Explain why some quarter-sawed lumber is always obtained when slash sawing.

19. Explain what is meant by the cutting speed of a saw, and illustrate how it is determined.

20. What is the smallest diameter of a log that will produce a stick of timber 8 inches square?

21. Give reasons why quarter-sawed lumber is generally more expensive to produce than common sawed.

22. How could we determine whether or not a board was sawed with a circular saw?

23. What is the advantage of the use of the gang saw?

24. Name some by-products that can be obtained from sawmill waste.

Summary

1. Trees are generally classified as endogenous and exogenous, as deciduous and evergreen, and as hardwoods and softwoods.

2. Endogenous trees do not have the ring structure. Exogenous trees are made up of annual rings.

3. Deciduous trees shed their leaves in the fall and generally have a broad leaf. Evergreen trees generally have needle-like leaves and are green all year round.

4. Individual trees are divided into roots, trunk, body or bole, and crown.

5. Trees grown in the open have large bushy crowns, and those grown in the forest have long trunks and small crowns because they receive sunlight only from the top.

6. The principal hardwoods of the North are oak, ash, hickory, beech, birch, elm, cherry, gumwood, basswood, and sycamore; and the principal softwoods are pine, hemlock, spruce, cedar, balsam, and tamarack.

7. In early times lumber was sawed out by hand, for the most part with the whip, or pit, saw. Later the power up-and-down saw was introduced, generally run by water. Next came the circular saw, in about 1870 in this country, then the band saw, and finally the double-edge band saw.

8. In a typical up-to-date large mill there are generally band saws, circular saws, gang saws, and slashers each doing its particular part.

9. There are two general kinds of sawing: common, or slash, sawing; and quarter, or vertical-grain, sawing.

10. In common sawing no effort is made to secure special grain effects. In quarter sawing the grain effect is of prime importance. Oak is the wood used extensively for quarter sawing because of its grain effect.

11. There are many types and sizes of sawmills ranging from small portable mills to large permanent plants.

12. In early times sawmills were often constructed in connection with grain mills or gristmills.

13. For the most part, at the present time, our larger mills are located in the Northwest and in the pine regions of the South.

14. Often dry kilns and planing mills are established in connection with large sawmills.

15. Lumber is generally designated as boards, planks, scantling, and timber. "Deal" is also a name used in England for large pieces that are intended for resawing.

SEASONING LUMBER

Reasons for Seasoning.—All wood is made up of cells and fibers varying in shape and size according

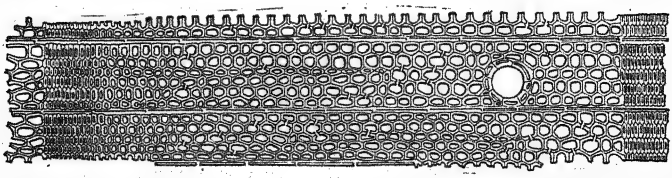

FIG. 28.—Cell structure of wood (microscopic). (*Courtesy of U. S. Forestry Service.*)

to the species and the conditions under which it grew (Fig. 28). When the trees are standing and in a normal condition, the wood is saturated with sap, which is often more than 90 per cent water. As soon as the surface of the lumber is exposed to the air, the sap begins to evaporate, causing the cell walls to

contract and the wood to shrink and often warp and check (Fig. 29). Shrinking cannot generally be controlled, but warping and checking can be prevented if certain scientific principles are observed when the lumber is seasoned. (In the chemical seasoning process recently developed it is claimed that the wood will not shrink.)

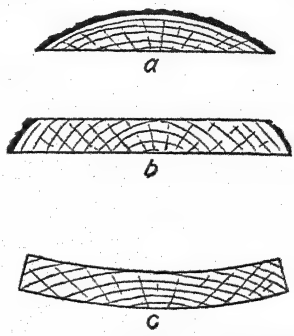

FIG. 29.—*a*. Slab. *b*. Edging board. *c*. Warped board.

Although wood has been used for all manner of construction since early times, little attention was given to scientific seasoning until the latter part of the past century. Lumber was so plentiful that waste mattered little. During the World War, however, the demand for all kinds of dry lumber became so great that the subject received special attention, with the result that improved methods were developed that have since become of special value for all kinds of woodworking industries.

Generally speaking, seasoning lumber means drying out the sap, although other changes take place that are of minor importance in wood used for general construction. The main purposes may be stated as follows: (1) to reduce the weight and therefore lessen the expense of handling and transportation; (2) to reduce the percentage of waste by eliminating warping, checking, and shrinking after it is put into use; (3) to reduce the quantity necessary to maintain in stock; and (4) to dry and otherwise make the lumber

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fit for construction purposes. A large percentage of lumber is shipped long distances, in some cases across the continent. Freight charges are based upon the ton per mile, and unless the lumber is properly dried before being shipped, the shipper must pay for the transportation of a large amount of water. In the

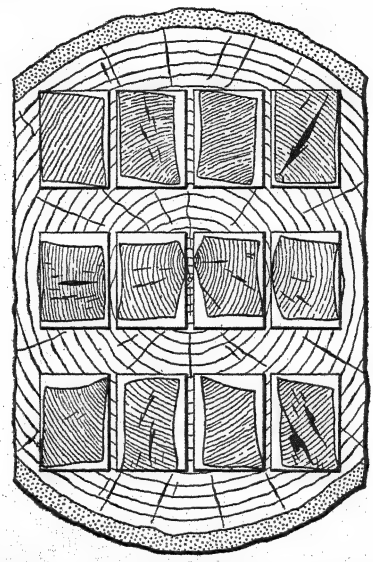

FIG. 30.—Cross-section of Southern swamp oak showing common drying defects. Taken from different parts of a log. (*Courtesy of U. S. Forestry Service.*)

second place, many firms use enormous quantities of lumber, which would necessitate keeping a large stock on hand if slow air drying were the only method used. This would naturally add to the overhead expenses and reduce profits. In the third place, when lumber is improperly seasoned, considerable waste will result from warping and checking. Shrinking in

drying cannot be prevented but all material can be thoroughly dried before it is put into fine construction. In the fourth place, lumber should not be put into fine construction unless it will remain sound and hold its shape permanently.

Open-air Seasoning.—There are three general methods of seasoning: open air, or natural, kiln drying, and chemical. In addition to these, wood is sometimes soaked in water or boiled in oil to season it for some special purpose. Open-air seasoning is the commonest and in some cases the cheapest method used for general standard lumber, although it will not ordinarily dry stock to a low enough moisture content for interior finish, furniture, and other fine construction. Wood seasoned in the open can never be drier than the air with which it is surrounded. Consequently it must be further dried by artificial means before it can be used for many purposes.

In open-air seasoning the piles or stacks are started on foundation timbers, or blocks, high enough from the ground to insure free circulation of the air (Fig. 31). The foundation should be so placed that one end of the boards will be elevated about one inch to the foot higher than the other to allow the water to run off. As a rule, only lumber of uniform thickness and length should be stuck in the same pile. The tiers, or layers, of boards are placed one above the other with narrow stickers (strips, sometimes called "crossers") placed at right angles between them to keep the boards separated and allow space for free circulation of the air. The stickers are placed at

either end of the pile and at close enough intervals to keep the boards from sagging. This arrangement serves not only to keep the tiers separated but also to hold the pile in position and to keep the boards from

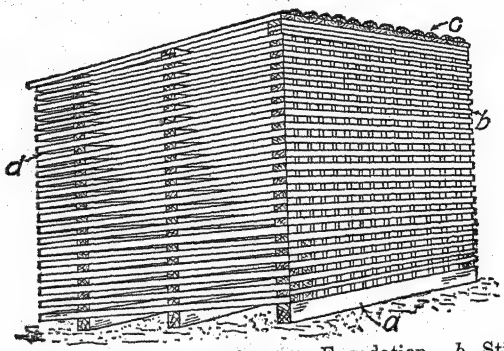

FIG. 31.—Open-air lumber seasoning. *a*. Foundation. *b*. Stickers. *c*. Roof. *d*. Tiers of boards.

warping by the viselike grip of the weight of the tiers above. At the front end of the pile the stickers should project a trifle beyond the ends of the boards to protect

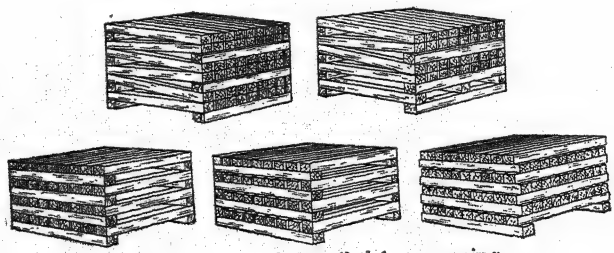

FIG. 32.—Railroad ties piled for seasoning.

them from the snow and rain. A temporary roof of poorer lumber is constructed as a protection for the top (often slabs serve this purpose better than boards). The time required for the air seasoning of ordinary

one-inch soft lumber is from three to four months in warm weather. Hardwoods require about six months of warm weather.

Artificial or Kiln Seasoning.—Because of the increasing demand for larger quantities and better quality of lumber, scientific, artificial seasoning has come to be of special importance. Government experts (as well as kiln manufacturers and mill men) are making a special study of the subject. There is a variety of special kilns on the market ranging in size from the hot box or oven in the small woodworking shop to large, elaborately equipped kilns owned and operated by the largest lumber companies. (Practically all large lumber producers operate dry kilns in connection with their sawmills.) Every woodworking plant of any size must have its private facilities where lumber can be redried on short notice to meet special demands.

As a rule, two general types of kilns are recognized: the charge, or compartment type; and the progressive type. Where a number of kilns are built together, they are called a "battery." In the compartment type the lumber is charged in, dried, and discharged before the next lot is introduced. In the progressive type green lumber is charged in one end (the receiving end) and gradually moved along, drying as it goes, until it is discharged at the other end dry (Fig. 33). As often as a car of dry lumber is removed another car of green lumber is introduced to take its place, keeping the process continuous; hence the name "progressive" kiln.

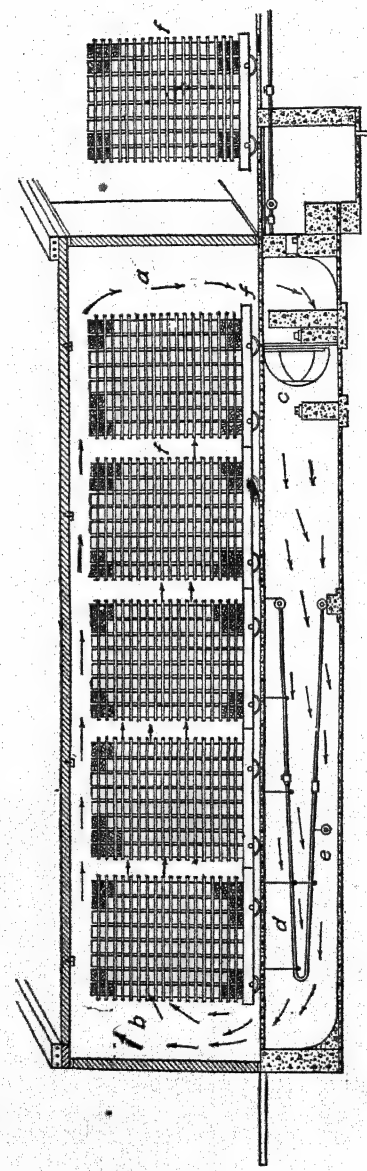

FIG. 33.—Modern lumber kiln. *a.* Vacuum end. *b.* Compression end. *c.* Fan. *d.* Steam coils. *e.* Spray. *f.* Cars of lumber. (*Courtesy of Universal Vacuum Dry Kiln Company.*)

If seasoning were merely a matter of drying lumber by applying heat, it would be a simple matter; but such is not the case. It is a well-established principle that, in order for wood to dry without checking or warping, the moisture content must be reasonably uniform from the surface to the interior. This can be accomplished only by keeping the surface moist until the interior is thoroughly heated and then drying the whole piece as nearly uniformly as possible. If dried too rapidly during the early stages of seasoning, the surface will check; while if dried too rapidly in the final stages of seasoning, honeycombing or hollow-horning (interior checking) is likely to result (Fig. 34).

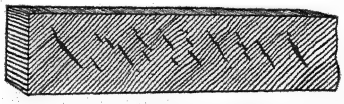

FIG. 34.—Lumber seasoning. Hollow-horning or honeycombing.

The main features of a typical, modern lumber kiln are a steam coil (or other means of supplying heat), water spray or steam jets for adding moisture to the air, and provision for keeping the air in circulation. In some cases, condensing coils are needed; and in the case of blower kilns, fans are installed to create circulation of the air. To produce the best results kilns should be operated only by experts. Many conditions arise where special judgment is called for. No two lots of lumber are apt to require exactly the same treatment. As with open-air seasoning, the kind and thickness and to some degree the quality of the lumber determine the length of time required. One-inch softwood requires from three to ten days in the kiln. Hardwoods require from ten to forty days.

AVERAGE DRYING TIME FOR ONE-INCH STOCK KILN-DRIED GREEN FROM THE SAW TO 5 PER CENT MOISTURE CONTENT

Species of Wood	Drying Time, Days
Yellow birch	14 to 19
Red gum, flat sawed	18 to 24
Sap gum	12 to 16
Mahogany	10 to 12
Sugar maple	15 to 22
Black walnut	20 to 24
Oak, red or white:[1]	
Northern highland stock	20 to 24
Northern lowland stock	24 to 30
Southern highland stock	24 to 30
Southern lowland stock	32 to 37

[1] Plain sawed only; quarter sawed dried under the same schedule takes about one-third longer. (*Courtesy of U. S. Department of Agriculture.*)

Special Seasoning.—In addition to regular standard lumber there are many articles that require special treatment in seasoning. Among the more common of these are hard maple blocks for shoe lasts and black walnut blocks for gun stocks. As a rule, these articles are first sawed and turned out in the rough from green wood. They are generally first air dried as far as is safe and then thoroughly seasoned in special kilns. The time required for kiln drying this class of work is from six weeks to three months.

NOTE.—The seasoned last blocks are purchased by last manufacturers who finish them according to styles ordered by the shoe manufacturers.

Wood that has been immersed in water for a long time before drying is less apt to warp than that directly from green trees. Very old woods of this character are much sought after for musical instru-

ments. It is reported that rare Stradivarius violins were made from old wood mud sills that had lain submerged in the Rhine River for over eight hundred years. Logs that have sunk in early drives and are recovered from the bottoms of rivers and lakes as a rule produce lumber that is exceptionally free from warping. Many logs of this character have been recovered from the upper Hudson River and other bodies of water. It is evident that this wood possesses qualities not found in lumber that has not lain in water before seasoning.

Boiling in oil is more of a special treatment after the wood is dry than a seasoning process. The oil penetrates the wood and modifies the subsequent moisture effect. Wooden plane stocks and members for high-grade wooden wheels are examples of articles sometimes seasoned in oil.

Experiments have proved that green wood previously soaked in certain chemical solutions will season without shrinking or surface checking. This is because the surface is prevented from shrinking by the solution and because the pressure of the vapor of the solution is less than that of the vapor of the moisture in the wood, which results in drawing or forcing the moisture from within to the surface, where it soon evaporates.

Several chemical solutions have been used with success for this purpose, the most common of which are sodium chloride (common salt), zinc acetate, borax, and baking soda. The process has proved especially valuable for seasoning large timbers that have always presented a difficult problem when

seasoned by ordinary methods because of their tendency to check. The time required for chemical seasoning is generally less than that required for ordinary seasoning. One curious fact is that the seasoning process goes on even while the wood is being soaked in the solution.

Seasoning-lumber Terms

air-dried lumber—Lumber seasoned in the open air.

air seasoning—Drying lumber in the open air.

apartment kiln—A kiln having more than one room. Same as compartment kiln.

artificial seasoning—Seasoning lumber with artificial heat.

baffle plate—An obstruction to deflect the current of air in a kiln.

blower kiln—A lumber kiln that is equipped with a fan to circulate the air.

case hardening—A set condition on the surface before the lumber is dry inside causing seasoned lumber to cup.

cells—Minute, elementary cavities in the structure of wood.

cell walls—Wood fibers that surround the cells in wood.

check or season check—A small split in wood due to uneven shrinking when seasoning.

chemical seasoning—Seasoning wood by immersing in some solution with a lower vapor pressure than that of water.

coarse grain—Lumber in which the annual rings are wide apart (from rapid-growing trees).

compartment kiln—Same as apartment kiln.

crossers—See Stickers.

cross-grain—Lumber in which the fibers of the wood are not parallel to the sides of the piece.

dew point—The temperature at which moisture-laden air gives up or deposits its moisture.

fibers—Minute, threadlike strings of wood composing the cell walls.

fine grain—Lumber in which the annual rings are close together (from slow-growing trees).

green wood—Wood in which the sap has not been dried out.

honeycombing or hollow-horning—Internal cavities in wood due to improper seasoning.

humidity—Moisture in the air.

kiln—A room or other special structure for artificial seasoning of lumber.

pores—Cavities in wood due to its structure.

progressive kilns—Lumber kilns that receive lumber at one end green and discharge it at the other end dry. Continuous kilns.

stickers—Narrow pieces of wood placed between the tiers of boards to allow for air circulation.

sticking up—Piling lumber properly for seasoning.

warp—Curve, twist, or bend in lumber due to uneven shrinking when seasoning.

Seasoning-lumber Questions

Group I

1. Explain the general structure of wood.

2. In general, what do we mean by seasoning lumber?

3. What happens when green wood is exposed to the air?

4. Give three reasons for seasoning lumber.

5. About when did scientific principles begin to be applied to seasoning lumber?

6. What effect did the World War have on the subject of lumber seasoning?

7. Name two types of lumber kilns, and explain how each operates.

8. Name the main features of a modern lumber kiln.

Group II

9. What is meant by green wood?

10. Mention places where unseasoned lumber can be used without doing harm.

11. Explain why wood checks when subjected to dry, hot air.

12. Explain why a piece of wood warps in drying.

13. Name some of the conditions that determine the length of time required for seasoning lumber.

14. Why is the blower kiln more efficient than the natural-draught kiln?

15. What special precaution must be taken with the blower kiln in respect to the air current?

16. Why must wood be dried before it is suitable for fine construction?

17. Explain why stickers should be narrow.

18. What should determine the thickness of the stickers?

19. Why should stickers be placed directly over each other?

20. What causes the air to circulate in the natural-draught kiln?

21. What does saturation mean in connection with air in lumber seasoning?

22. Why is open-air seasoning often more expensive in the city than in the country?

23. From which direction should the air current come in a blower kiln—from the green end or from the dry end? Explain your answer.

24. What would increase the humidity in a kiln aside from steam jets or water spray?

25. Why is a recording thermometer more useful in connection with lumber-kiln operation than an ordinary thermometer?

26. Why is steam generally more suitable for furnishing heat to a lumber kiln than direct heat from gas or coal?

27. Why does a board warp with the concave side upward when dried on the ground?

WOOD PRESERVATION

Historical.—The practice of wood preservation is of comparatively recent date. In early times wood was sometimes charred, smoke cured, or painted with pitch or some other material to make it last longer,

but we have no evidence that the practice was carried out scientifically or to any great extent. As early as 1815 a process of treating wood by soaking it in a solution of zinc chloride was developed. While this method was more efficient than simply coating the surface, the penetration was never deep enough to prevent the wood from decaying within. In 1838 the Burnett process was developed whereby the wood was immersed in air-tight cylinders with zinc chloride solution under pressure until the desired penetration was secured. This process proved to be very efficient, and the principle involved is the same as that used in the standard treatment processes of today.

Development.—So abundant and inexhaustible did the forests of our country seem to be that very little attention was given to the subject of wood preservation until the early part of the present century, when the scarcity of lumber and other forest products began forcibly to call our attention to the necessity of adopting a more conservative policy in the use of wood. The railroads, being among the largest users of wood in the form of cross-ties, piles, timbers, etc., were naturally among the first to become interested in the subject of wood preservation. At first, one or two of the roads established small experimental plants for treating ties for their own use. These proved so successful that the industry rapidly developed. At the present time, many of the leading roads not only have plants of their own but also have a considerable percentage of their treating done by independent concerns that do the work on a commercial basis.

The industry has been developed not only by the railroads and other private interests but also by the federal government, which has carried on extensive experiments and has done much to promote the advancement of the industry.

Causes of Wood Decay.—Before discussing different processes of treating, we should first learn something about the causes of decay in the wood. Scientists tell us that the decay is the result of minute plant growth which attacks and destroys the fibers and that if this growth is prevented, decay will not take place. The enlarged fruitage of this growth or fungus can often be seen on the surface of decayed wood. Decay thrives best in warm and damp places, in consequence of which railroad ties, piles, telegraph poles, paving blocks, and the like in contact with the ground are especially exposed to attack. Next to decay, insects are the most destructive agents in woods. This is not only true in the tropics, where white ants often eat the entire substance away, but also in colder climates, where ants, termites, borers, beetles, and other insects chew holes in the wood, thus weakening it and exposing larger portions to the fungus attack. Fortunately, however, most preservatives that will prevent decay will also insure against the attacks of insects.

Preservatives.—The main problems to solve in efficient wood preservation are (1) to find a disinfectant that will prevent and kill fungus growth, that will not injure the wood, that will be sufficiently durable, and that will be cheap enough to permit of its use in

large quantities; and (2) to find a process by which the preservative can be forced into all parts of the wood where decay is likely to take place. There are several such preservatives on the market, among the most common being creosote oil (a coal-tar derivative), petroleum and creosote mixtures, tar-creosote mixtures, and chemicals such as zinc chloride, mercury chloride, Wolman salts, and other fluoride solutions. Opinions differ as to which of these preservatives is the best to use for certain kinds of work. As a rule, creosote oil or its mixtures are used most extensively for treating railroad ties. Zinc chloride was formerly used to a considerable extent for the purpose, especially in the arid regions of the Southwest, but its use at the present time is limited. The two-mile Shands Bridge across St. Johns River in Florida offers a good example of creosote treating on timbers and piling. Fluoride solutions are used more especially for treating where the wood should not be stained and where the surface is afterward to receive coats of paint. The board walks of Coney Island and Rockaway beaches are examples of construction treated with Wolman salts. The practice of treating wood for parts of better grades of buildings is coming more and more into use.

Coal-tar creosote is the most effective and generally useful wood preservative. Its importance to the wood-preserving industry is evidenced by the fact that the demand has usually been greater than the supply. Over 217 million gallons were used for treating wood in a recent year, of which about 40 per cent was imported. Its advantages are (1) its high toxicity, which make it very poisonous to

wood-destroying fungi; (2) its relative insolubility in water and low volatility, which impart to it a great degree of permanence; (3) its ease of application; (4) the ease with which its depth of penetration can be determined; and (5) its general availability and relatively low cost.[1]

Methods of Treating.—There are three general methods of applying preservatives to wood: namely, (1) the superficial methods, as brushing, spraying on the surface, and dipping; (2) hot and cold baths; and (3) pressure. The brushing and spraying methods are not very efficient, because only the surface is covered. They are sometimes used for treating the ends of poles, posts, and other utilities where the more expensive treatment by pressure would not be practicable (Figs. 35, 36).

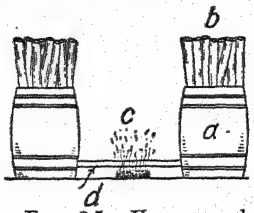

FIG. 35.—Homemade fence-post-treating apparatus. *a*. Barrels. *b*. Fence posts. *c*. Fire. *d*. Iron pipe.

Dipping, sometimes called the "absorption" method, is often used for treating the butts of poles, piling, posts, small quantities of ties, dock timbers, etc., where a pressure process is not available or would be too expensive. The articles are dipped, soaked, or sometimes boiled in an open tank or some other suitable container until the desired amount of preservative has been absorbed and then removed and allowed to drain. In the hot and cold methods the preservative is applied hot for two or three hours. The pores are thereby

[1] Courtesy of U. S. Department of Agriculture.

opened, and the penetration becomes deeper; and if at the end of the hot bath the articles are suddenly submerged in a cold bath of the same preservative for about the same time. the results will be still more satisfactory.

The most effective method of treating is by the use of pressure or pressure and vacuum combined. There are several standard pressure methods of treating in use, differing from each other in certain details but all involving the same general principles. Among the most common of these processes are the Burnett, the Rueping, the Bethell, the Card, the Lowry, and the Wolman processes. They are also designated as full cell and empty cell according to the amount of preservative left in the wood. Brief descriptions of treating railroad ties will serve to give an idea of the steps in typical pressure methods. In all cases the wood should be thoroughly air seasoned before treating, and in some instances a preliminary steaming is especially beneficial.

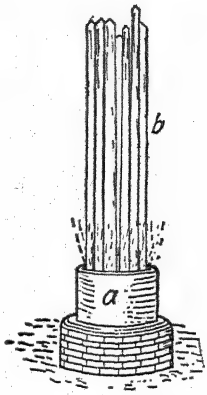

FIG. 36.—Pole-treating apparatus. *a*. Treating tank. *b*. Poles.

Burnett (Full-cell) Process.—(1) Run ties into the cylinder, and close and seal the door. (2) Draw a vacuum for about half an hour. (3) Apply hot zinc chloride at 150°F. or more until the ties are completely submerged. (4) Apply pressure of 100 to 175 pounds

per square inch until sufficient absorption has taken place. (5) Release pressure; draw final vacuum to remove surplus preservative.

Wolman Process.—The only difference between the Burnett and the Wolman processes is that the Wolman process uses Wolman salts instead of zinc chloride.

Rueping (Empty-cell) Process.—(1) Run ties into cylinder; close and seal the door. (2) Apply pressure to force air to penetrate the wood (from 75 to 100 pounds). (3) Submerge the ties in creosote oil under pressure. (4) Increase pressure to about 200 pounds, and hold until proper penetration has taken place. (5) Release pressure, and draw vacuum to remove surplus preservative.

Lowry Process.—(1) Wood is air seasoned. (2) Pressure is applied (about 180 pounds) to saturate the pores. (3) Quick vacuum is produced and maintained from one to two hours.

The kinds of wood most generally used for railroad ties in the United States are long-leaf yellow pine, oak, and chestnut. Since the practice of tie treating has become universal, beech, birch, hard maple, ash, gum-wood, and other woods heretofore unsuitable because of their tendency to quick decay when untreated have been quite extensively used.

The amount and kind of preservative used varies with different kinds of wood and the use for which they are intended. The following is a brief table of some of the more common treating processes for ordinary woods:

Process	Kind and Amount of Preservative
Burnett.....	Dry zinc chloride, ½ pound per cubic foot of wood
Card.....	Dry zinc chloride, 3 pounds per cubic foot of wood
Rueping....	Creosote-tar solution, 5 to 6 pounds per cubic foot of wood
Lowry.....	Creosote-tar solution, 8 to 12 pounds per cubic foot of wood

When creosote-petroleum mixtures are used the proportions are about fifty-fifty, and the amount is from 8 to 16 pounds per cubic foot of wood.

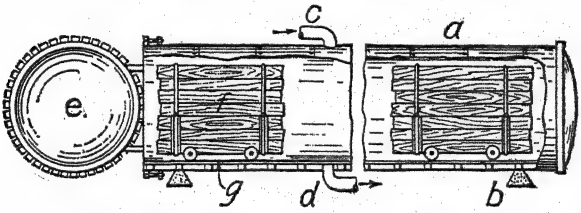

FIG. 37.—Railroad-tie-treating cylinder. *a*. Steel shell. *b*. Foundation. *c*. Preservative inlet. *d*. Drain or outlet for surplus preservative. *e*. Air-tight door. *f*. Carload of ties. *g*. Tracks.

Equipment.—Treating equipment varies from small retorts a few feet in length and diameter to huge cylinders over 160 feet in length and 9½ feet in diameter (Fig. 37). The larger ones will accommodate about 1,200 ties to a batch and turn out between 4,000 and 5,000 ties in twenty-four hours. Some of the largest plants are equipped with several large cylinders and have capacities ranging from 12,000 to 15,000 ties per day.

If the best results in treating are to be obtained, the work must be carefully and scientifically done. The wood must be properly seasoned before the preservative is applied, the preservative must be of the

suitable kind and proper temperature, the pressure neither too little nor too great, and the time of treating such as to allow for ample penetration.

The whole subject may be considered largely one of economics because of its effect on our forest supply and also its relation to the many industries that touch our everyday life and rely upon wood for their raw materials.

Wood-preservation Terms

absorption—The action of sucking or taking in a solution by a substance.

brush process—Applying the antiseptic solution to the surface of wood with a brush.

coal tar—A black, sticky, fluid substance obtained from the distillation of bituminous coal.

creosote oil—A black, oily disinfectant obtained by the distillation of coal tar.

cross-ties—Strong pieces of wood, either squared or flatted on two sides, used to support the rails of a railroad.

cylinder—The large cylindrical tank in which pressure timber treating is done.

decay—Decomposition, rot.

empty-cell process—The treating process in which the surplus preservative is drawn from the wood with a vacuum.

full-cell process—The treating process in which the cells of the wood are left full of preservative.

fungus—Minute plant growth, mildew, causing decay in wood.

impregnation—Penetration or saturation of the wood with the disinfectant.

non-pressure method—Treating wood to prevent decay by brush application or by dipping the articles in atmospheric pressure only.

pressure method—Treating wood by forcing the preservative into the fiber with pressure.

preservative—Any liquid or other material used to preserve wood.

tie treating—The process of treating railroad ties with a preservative.

vacuum—The space in an air-tight container from which all the air or other gases have been removed.

vulcanize—The process of heating wood to about 500°F. to prevent decay.

Wolman salts—A solution of sodium fluoride, dinitrophenol, and other chemicals used for wood preservation.

zinc chloride—A disinfectant solution obtained from a compound of zinc and chlorine sometimes used for wood preservative.

Wood-preservation Questions

Group I

1. What is the cause of decay in wood?

2. What is the nature of decay?

3. How was wood sometimes treated for preserving in early times?

4. Next to decay what other agents are most destructive to wood?

5. About what year was the first pressure process invented? What was the name of the process, and what was the preservative used?

6. What is meant by a preservative? Name some of the most important preservatives used for treating wood.

7. Name the most important qualities that a wood preservative should possess.

8. Why is it better sometimes to apply a preservative hot?

9. Name several other wood articles besides railroad ties that naturally need preservative treatment.

10. Explain what is meant by a vacuum, and state how it is created.

11. What kinds of woods are most commonly used for railroad ties?

GROUP II

12. Under what conditions will decay take place most readily?

13. Why are railroad ties apt to decay rapidly unless treated?

14. How does treating railroad ties affect the forest?

15. What is meant by atmospheric pressure? What is "ten" atmospheres?

16. Explain how tie treating increases the number and kinds of woods that can be used for ties.

17. Explain how both pressure and vacuum assist in preservative treatment.

18. Why is boiling wood in a preservative sometimes better than simply soaking?

19. Give two reasons for painting a house.

20. What is meant by a full-cell process; an empty-cell process?

21. Why were the railroads apt to be among the first to take up wood preservation?

VENEER

Veneer is a thin piece or slice of wood sawed or shaved from a log or a flitch. Formerly only expensive woods were used in its manufacture. It was worked out by hand, its cost being thus increased, and only the rich could afford it. In modern times, however, it is found in the construction of a large variety of articles; and veneer cutting has become one of the important branches of wood-consuming industries. It is estimated that at the present time over forty varieties of foreign woods as well as a large number of domestic woods are cut into veneer in this country.

Rotary Cutting.—There are three general methods of cutting veneer: rotary cutting, slicing, and sawing. The largest percentage is cut by the rotary method, because it is the cheapest and produces material

suitable for many kinds of work, and in some instances special grain effects. The rotary veneer machine is a huge turning lathe with a long, rigid knife adjusted in a bedpiece level with and parallel to the axis of the log being cut (Fig. 39*A*). Two huge spindles having both rotary and horizontal movements are attached to the machine in such a position that they can be advanced and forced into the end of the log and cause

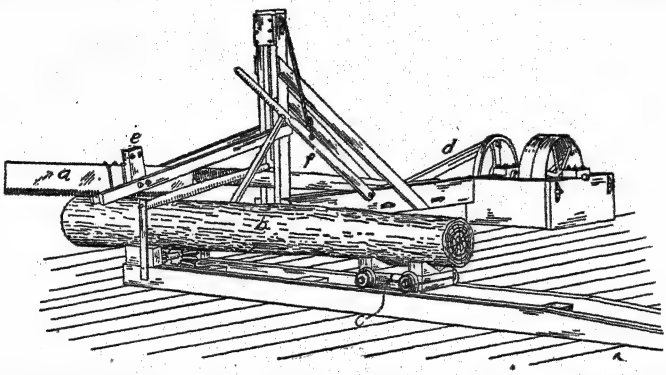

FIG. 38.—Drag-saw cutting bolts. *a*. Saw. *b*. Log. *c*. Carriage. *d*. Pit man. *e*. Guide. *f*. Arm. (*Courtesy of Defiance Machine Works.*)

it to revolve. The logs are first steamed, or boiled, from twelve to thirty-six hours to soften the fibers and make the wood tough and pliable. If the wood is light colored and it is desired to keep the veneer unstained, steaming is used; if it is dark, the logs are generally boiled.

After softening, a log is adjusted between the spindles endwise and started revolving against the knife. The knife has a slow, uniform, sidewise motion toward the center and shaves off a continuous sheet of veneer as the log turns, the process closely resembling

the unrolling of paper from a roll. As the veneer leaves the machine it is trimmed and clipped to desired dimensions and goes to the drying room. In regular rotary cutting a portion of the log (a core) unsuitable

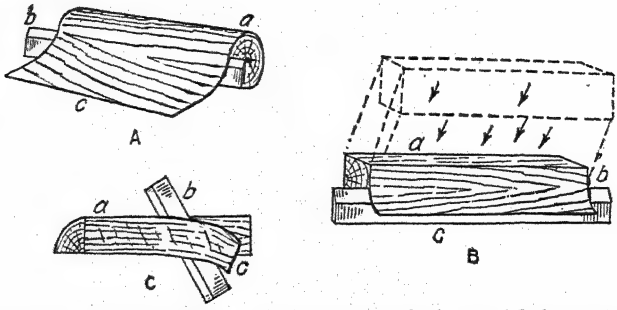

FIG. 39.—Veneer cutting. *A*. Rotary method. *B*. Modern slicing method. *C*. Earlier slicing method. *a*. Log or flitch. *b*. Knife. *c*. Veneer.

for veneer is always left in the center. This core is generally sawed into lumber for packing crates or other purposes where high-quality material is not required or is used as fuel for the boilers.

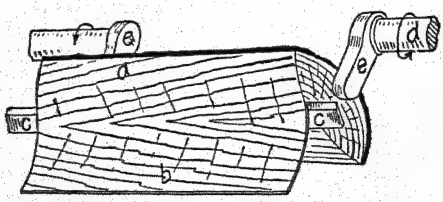

FIG. 40.—Early method of veneer slicing. *a*. Flitch. *b*. Veneer. *c*. Knife. *d*. Spindle. *e*. Crank or offset.

A special method of rotary veneer cutting is done with an attachment on the regular rotary machine. An older attachment of this sort consists of two heavy crank arms (offsets) adjusted one on either spindle and parallel with each other (Fig. 40). The flitch is

frame with a movable bedpiece to which is attached a strong, horizontal knife. A horizontal staylog (flitch carrier) works up and down diagonally in guides past the knife. The flitch is dogged to the staylog, and at each downward stroke a slice of veneer is shaved off (Fig. 39*B*). After each stroke the flitch moves toward the knife the thickness of the veneer and is in position for the next cut.

Another and older type of veneer-slicing machine is one in which the knife moves instead of the flitch. This machine consists of a rigid frame with a bedpiece upon which the flitches are dogged. A heavy knife moves diagonally along the edge of the bedpiece and shaves off the slices of veneer in similar manner to slicing cheese in a cheese cutter (Fig. 39*C*). Woods most commonly cut by slicing are mahogany, quartered oak, quartered sycamore, and curly walnut. As with special rotary cutting, beautiful grain effects can be obtained by slicing stumps of trees, large roots, knots, and burls.

Sawing.—Steaming and boiling are detrimental to veneers from certain kinds of wood. To avoid their use, circular sawing is resorted to. Veneer sawing does not differ in many respects from sawing regular lumber with the circular saw (Fig. 41). The saw used, however, is a very flat cone and tapers from about an inch in thickness at the center to a periphery or rim thickness of about one-sixteenth of an inch. The flat side of the saw runs against the log, and the tapered side against the veneer. As soon as the veneer is cut, it bends outward, allowing the thick

part of the saw to pass through the kerf without binding (Fig. 41). In sawing veneer one-sixteenth of an inch thick, at least 50 per cent of the wood is wasted in sawdust.

Methods of Drying.—Before veneer can be used it must be thoroughly dried. This is done either in an open drying room artificially heated or in a special veneer-drying machine. In the open drying room

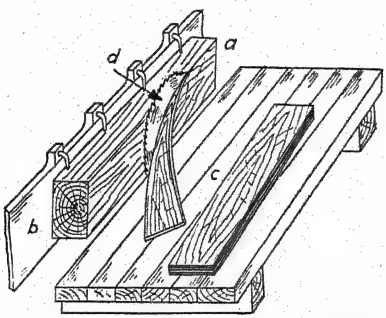

FIG. 41.—Veneer sawing. *a.* Flitch. *b.* Carriage. *c.* Veneer. *d.* Circular saw.

the sheets are stood edgewise in upright racks resembling a picket fence which allows free circulation of air. Ordinarily woods, cut from twenty to thirty-two to the inch, can be dried overnight by the method, but veneers thicker than this (especially hardwoods) require longer. A typical drying machine is a large reinforced rectangular structure from 50 to 100 feet long, about 10 feet wide, and 8 feet high, covered with asbestos board and galvanized iron. Extending from one end to the other in the interior are five or six rows of rolls, parallel with each other and placed horizontally across the width dimension of the box. Between

these rolls steam coils are installed to furnish the heat. When the machine is in operation, the rolls have a slow revolving movement which enables them to pick up the pieces of veneer at the receiving end and pass them slowly along to the discharging end. The action is much like that of an ordinary clothes wringer. The time required for drying in this machine is from one-half to one hour depending upon the kind of wood and thickness of the veneer. In another type of drier the veneer is carried through by an endless-link belt.

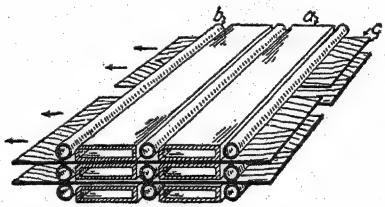

FIG. 42.—Veneer drying. *a.* Hollow steam-heated plates. *b.* Rolls. *c.* Veneer. (*Courtesy of Merritt Manufacturing Company.*)

Another type of artificial veneer drier uses flat hollow plates for heating instead of steam coils. This machine consists, in the main, of a deck of hollow steam-heated plates arranged in banks of six plates each, one above another. Between the plates and alternating with them are rolls for passing the veneer along (Fig. 42). The sheets are fed into the receiving end and pass to the first set of plates, which come together and flatten and heat the veneer much in the same manner as a clothes-pressing machine flattens a piece of cloth. The pressure of the plates is released every few seconds, and the sheets are passed along to the next bank of plates, and so on until they are

dry. The time required for drying in this machine is less than is required in other types; but this, of course, is also modified by the kind of wood and thickness of the veneer. Machines are constructed with extra sets of plates for drying thicker veneers.

General Uses of Veneer.—A large part of the veneer manufactured goes into plywood panels, which are being used increasingly for walls, ceilings, wainscoting, doors, and other parts for interior building construction; also, for outside coverings for buildings, for concrete forms, billboards, house trailers, boats, large containers, and other purposes where strength, large size, durability, and, often, beauty are of special importance.

The problem of securing a glue or bonding material that would stand up when the panels were exposed to dampness or excessive heat formerly limited the use of plywood to interior, well-protected work. But recently a phenolic resin has been used for the bond that not only renders the work proof against all ordinary dampness or heat but also permits its use in actually wet places and for exterior finish for all kinds of weather conditions. The bonding resin comes in thin sheets and is cut to size and interleaved with the veneer sheets and subjected to pressure between hot plates in a hydraulic press, or it can be purchased in liquid form. Plywood panels can be purchased in a variety of stock sizes, among the most common of which are 32 and 48 inches in width, to accommodate the spacing of studding and joists in building construction, and, in length, ranging up to 12 feet. In con-

structing these panels the plies, or pieces, are placed with their grain running at right angles to each other to ensure strength and to guard against warping and checking. The two outside layers or plies are called "face" and "back," respectively; and the center piece, the "center," or "core." If additional plies are used they are called "cross-banding" and are always placed

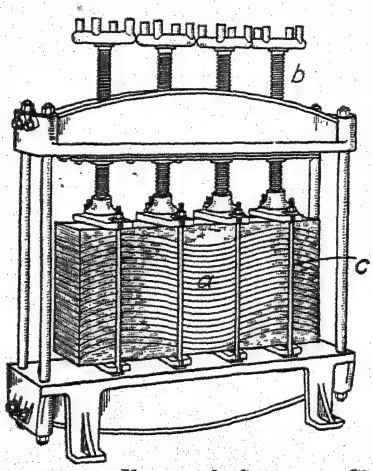

FIG. 43.—Veneer press. *a.* Veneer. *b.* Screw. *c.* Clamps. (*Courtesy of Charles E. Francis Company.*)

so that their grain will run at right angles to the pieces next to them. Glued-up veneer construction is especially adapted for curved and irregular work and where strength and rigidity are required (Fig. 43). The curved edges of grand pianos, chair seats and backs, drawer fronts, etc., are good examples of this class of work. Many of the cheaper grades of veneer are made into wooden dishes, fruit baskets, crates, and other containers.

Veneer Terms

backing—The back piece of veneer on plywood or panels.

bleaching—Subjecting veneer to the fumes of sulphur or other bleaching compound to lighten the color.

burl—A large swelling or knot on a tree trunk, with irregular grain.

center stock—The core or center piece of plywood.

clipping—Cutting veneer to dimension in a clipper or clipping machine.

core—The central part of the log after the veneer has been cut off. Also center stock of plywood.

cross-banding—Extra pieces of veneer between the center stock and the face and back pieces.

dimension stock—Veneer cut to definite size.

drying machine—A large, enclosed, rectangular, boxlike machine supplied with hot rollers for moving and drying the veneer.

facing—The front piece of plywood, or panels.

flitch—A longitudinal section of a log from which veneer is cut.

machine run—Veneer as it comes from the machine before it has been sorted.

matching—Jointing two pieces of veneer together to produce special grain effects, as on a panel.

panels—Plywood used for panels, as door panels, etc.

peelers—The name given to blocks or sections of logs from which rotary-cut veneer is cut or peeled.

plywood—Three or more thicknesses of veneer glued or cemented up into panels or boards.

rotary cut—Veneer cut in a rotary veneer-cutting machine. Veneer from around the log.

spindle—The revolving strong steel support, supplied with spurs, for holding and revolving the log in rotary cutting.

veneer—A thin sheet or slice of wood.

veneer flitch—A pile of veneer cut from a flitch and piled just as it comes from the knife in the same relative position in which it was in the flitch.

veneer press—A strong press for gluing up plywood or panels.

Veneer Questions

Group I

1. Why is boiling or steaming necessary before cutting veneer?

2. Under what condition should pieces for veneer be boiled? Under what condition should they be steamed?

3. What are some of the thicknesses for standard veneer?

4. Name and explain the three common types of veneer cutting.

5. What kinds of wood were formerly used for veneer? How was it generally cut out?

6. What use is generally made of cores left from rotary veneer cutting?

7. What does rotary veneer cutting resemble in the paper industry?

8. Explain the arrangement of an open-air veneer-drying room.

9. Why is the grain of the different pieces in plywood placed at right angles?

Group II

10. Name special advantages in the use of veneer.

11. Why is veneer especially good for curved work?

12. Mention articles in the ordinary home involving the use of veneer in their construction.

13. What would determine the length of a veneer dryer?

14. How wide can rotary-cut veneer be obtained? Illustrate.

15. Why must cores always be left of the center of the logs when cutting with the rotary method?

16. How wide a piece of veneer can be obtained from a flitch?

17. Why is veneer obtained from roots and burls especially beautiful?

18. In general what factors would govern the thickness that veneer should be cut?

19. Why is it generally desirable to cut veneer as thin as practicable?

20. What would determine the length of time a log should be boiled or steamed before cutting?

21. Explain why a veneer saw should be very thin.

22. Illustrate the operation of a veneer saw that is thick at the center and thin at the rim (teeth).

23. What determines the length of time required for drying veneer?

24. If a log is 21 inches in diameter how wide a piece of veneer can be obtained by going once around?

25. In rotary cutting is the log a perfect circle?

26. Why must the knife be gradually moved toward the center when cutting by the rotary method?

27. What is meant by matching up veneer? Give examples where this would be done.

COOPERAGE

Everyone is familiar with wooden barrels, kegs, tubs, and pails used for containers. This class of

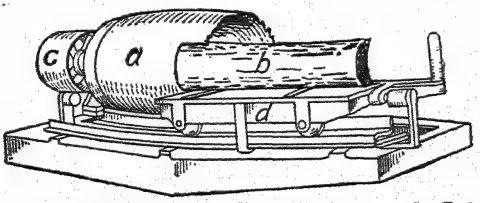

FIG. 44.—Barrel-stave saw. *a.* Cylindrical saw. *b.* Bolt of wood. *c.* Pulley. *d.* Carriage. (*Courtesy of E. and B. Holmes Machinery Company.*)

utilities is known as "cooperage" and is constructed of staves, headings, and hoops. There are two general branches of the industry: "slack cooperage" and "tight cooperage."

Slack Cooperage.—Slack cooperage is used for dry commodities, as salt, sugar, flour, cement, fruit, and vegetables, and need not be very strong, as it is generally used but once. For this reason it can be

constructed of any cheap, sound wood. At the present time, red gum, beech, and southern pine are the leading woods used for slack-cooperage staves and heading; and elm is the wood sought for hoops.

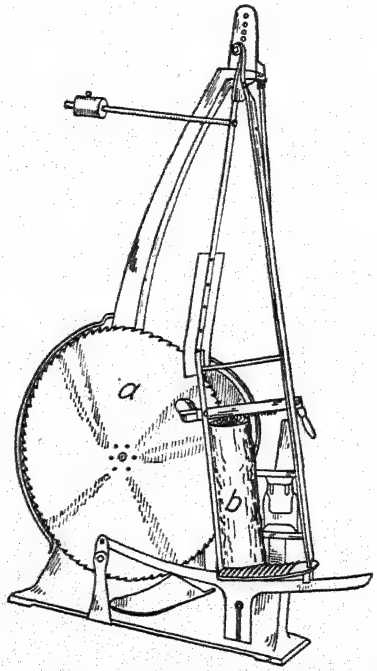

FIG. 45.—Heading saw. *a*. Circular saw. *b*. Bolt of wood. (*After Brown.*)

(Flat steel and wire hoops are rapidly taking the place of wood for slack-cooperage hoops.)

There are two general methods of cutting staves for slack cooperage, namely, with a special stave-cutting machine and with a cylindrical stave saw. The stave machine works somewhat on the same principle as the rotary machine for cutting veneer. After stave bolts

are thoroughly steamed they are clamped in the machine to a tumbler, and at each stroke a stave is cut off. The process is very rapid, and a good machine in the hands of an expert workman can turn out about forty thousand staves a day. In the sawing method the bolts are clamped to a carriage and sawed with a cylindrical barrel saw with a diameter practically the

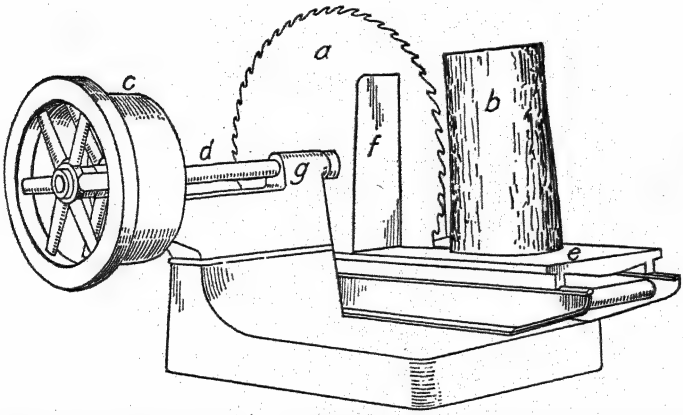

FIG. 46.—Heading saw. *a*. Circular saw. *b*. Bolt of wood. *c*. Pulley. *d*. Shaft or arbor. *e*. Carriage. *f*. Guide. *g*. Bearing. (*Courtesy of Defiance Machine Works.*)

same as that of the finished product, which gives the staves the proper curve (Fig. 44). After the staves are cut out they are jointed on a special jointing machine and are ready to be packed and shipped. Heading is sawed from short bolts on special machines (Figs. 45, 46), and hoops are sawed from straight-grained stock and afterward planed or shaved to shape and size.

Often the three parts of the barrel (staves, heading, and hoops) are manufactured in different parts of

the country and shipped in shooks (bundles) to some distributing point for assembling near where the containers are needed. Because of this practice numerous barrel factories formerly sprang up in the larger apple-growing sections and elsewhere. In the past few years, however, baskets, crates, and other containers have largely taken the place of barrels for apples, so that this branch of the industry is no longer of so much importance. Sugar refineries, salt works, flour mills, and other industries using slack cooperage in large quantities generally have barrel factories connected with them.

Fig. 47.—Frow. Early method of splitting staves, shingles, etc.

Tight Cooperage.—Tight cooperage comprises barrels and other stave containers for holding liquids. The stock selected for this branch of the industry must be of higher quality than that for slack cooperage. In the early days first-quality white oak was almost always used, but, as this wood became scarcer and harder to obtain, other woods, as red oak, red gum, ash, and pine, were substituted, especially for barrels for oil, turpentine, molasses, and other products which are not affected by the nature of the wood in which they are contained.

Formerly tight cooperage staves were rived (split) out by hand, sometimes with a frow (Fig. 47), but this practice often resulted in a waste of from 50 to 60 per cent of the wood. At the present time they are prac-

tically all sawed on the stave saw, but even with this method there is more or less waste, as only the best parts of sound trees can be used. Sometimes the top and other parts of the trees unsuited for staves are worked into railroad ties, slack-cooperage parts, and other utilities not requiring wood of so high quality. Flat steel hoops are almost universally used for tight cooperage, but in certain cases where the containers are to be used for vinegar or other highly acid commodities wooden hoops are still employed. The bulk of the white-oak timber still used for tight cooperage comes from our Southern-central states.

Substitute for Cooperage.—On account of the increasing cost of wood cooperage, the tendency is to substitute other containers when possible. Pasteboard cartons, paper sacks, and cloth bags are taking the place of slack cooperage; and steel barrels, drums, and tin cans are being used in many places where tight cooperage was formerly required.

Cooperage Terms

bilge—The central part of a barrel, at its largest diameter.

cask—A barrel-shaped wooden container made of staves, hoops, and flat heads.

chime—The projecting ends of the staves extending beyond the head of a barrel.

cooperage—The industry of making barrels and other stave containers.

cull staves—Defective or poor quality of staves.

firkin—A small wooden barrel, generally used for butter or for lard.

heading—The pieces comprising the ends of barrels or other stave containers.

hogshead—A large barrel or cask holding from 60 to 140 gallons.

keg—A barrel-shaped container holding about 10 gallons.

sawed staves—Staves roughly sawed out with a stave or cylinder saw.

shook—A bundle of staves, or heading, ready to be set up.

slack cooperage—Barrels and other stave containers made for holding only dry materials.

split staves—Staves roughly split out (generally of high grade for tight cooperage).

stave saw—A cylindrical or barrel saw for sawing staves with the proper curve.

tight cooperage—Barrels and other stave containers constructed for holding liquids.

Cooperage Questions

Group I

1. Explain what is meant by a cask.

2. Explain what is meant by "slack" cooperage and "tight" cooperage.

3. What character of wood can be used for slack cooperage? What must be the character of the wood used for tight cooperage?

4. Name some of the containers that are taking the place of slack cooperage; of tight cooperage.

5. How are the staves for slack cooperage formed?

6. Name commodities that are put up in slack cooperage; in tight cooperage.

Group II

7. Why are split staves generally of better grade than sawed staves?

8. How many times is slack cooperage generally used? Explain your answer.

9. Why do barrels for containing acids generally require wooden hoops?

10. Explain why a cylindrical saw should be used for making staves instead of a straight saw.

PAPER

In general paper can be considered a tissue of matted vegetable fibers that have been deposited from suspension in water by means of a fine screen or sieve and afterward pressed and finished by passing through rollers. The subject is so vast and varied that only a few of the more common phases of the industry can be considered in this connection.

Historical.—It is reported that the Chinese made paper from the fibers of the bamboo plant as early as two hundred years before the Christian era. An important epoch in the industry dates back to 676 A.D., when the Arabs captured Samarkand, afterward known as Russian Turkestan. The Caliphs of Bagdad fostered all forms of industry, and as a result the city of Bagdad became famous as a paper-making center. The first use of rags for paper making is also attributed to the Arabs, who kept the process secret until the time of the Crusades, when it was discovered and a paper industry was established at Auvergne, France. This may be considered the beginning of the paper industry in Europe. In 1085 the Moors made paper in Spain. In Holland, Huguenot refugees made the famous "Dutch" paper which became in great demand. The earliest paper mill in England seems to have been established by John Tate in 1490. The first edition of Shakespeare's plays is supposed to have been printed on paper made by John Seilman, a German, in 1588.

In America the industry was started in 1690 in Philadelphia by William Rittenhouse. Little improvement was made in it until 1799, when Nicholas-Louis

Robert, a Frenchman, who by the way fought in the American Revolution under Lafayette, invented a continuous paper machine and named it the "Fourdrinier" after a man by that name who had developed the process in England. Robert's machine could turn out a continuous roll of paper fifty feet long, as compared with a modern Fourdrinier machine which will produce a sheet of paper of unlimited length and as large as can be handled.

With the spread of education about the middle of the past century the supply of rags for paper making became inadequate, and another source of pulp supply had to be found. The problem was partially solved in 1840 by Keller, a German, who discovered that by grinding wood against a stone revolving in water a pulp could be produced which, although inferior to that from rags, could be mixed with rag pulp and would produce a good grade of paper. In about 1865 Tiligman, a Philadelphia engineer, the inventor of the sand blast, discovered that cellulose fibers could be separated from the other material in wood by boiling in sulphurous acid. It is reported that he accidentally discovered this when stirring sulphuric acid with a match stick. The principle is the same as that used at the present time by the large paper companies.

Pulp.—There are four general processes in the production of paper: (1) preparation of fibrous materials, (2) converting the materials into pulp, (3) forming the web or sheet paper, and (4) finishing.

Pulp, the fibrous material, is obtained from a variety of sources such as wood, rags, hemp, jute, manila,

cordage, esparto, and straw. Wood pulp is most extensively used and is obtained either by grinding bolts of wood or by the action of certain chemicals on wood chips. Among the most important varieties of wood used are softwoods, as spruce, hemlock, fir, and pine. Hardwoods such as poplar, gum, beech, birch, and maple are used to a lesser degree. In the production of pulp from materials other than wood, several

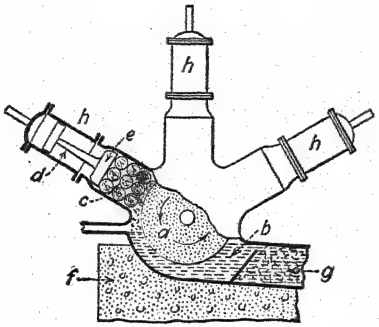

FIG. 48.—Three-pocket pulp grinder. *a.* Grinding wheel. *b.* Water. *c.* Bolts of wood. *d.* Piston. *e.* Plunger. *f.* Concrete foundation. *g.* Pulp and water. *h.* Cylinders.

preliminary steps are necessary before the pulping process begins. As a rule the materials are first cut into pieces of suitable size, dusted, and thoroughly washed to remove all dirt. The pulping process consists in cooking the prepared materials under pressure in some sort of chemical solution which dissolves the lignin and other intercellular matter and leaves practically pure fibrous cellulose behind. The solution most generally employed is caustic soda, although other chemicals are also used.

Groundwood Pulp.—In the production of groundwood, bolts of barked, or rossed, wood are pressed by

hydraulic plungers against rapidly revolving grindstones in casings in water that reduce them to a fine, fibrous, pulpy mass (Fig. 48). Groundwood pulp contains lignin and other impurities that make it cheaper and inferior to chemical pulps. Its principal uses are in newsprint and other lower grades of paper.

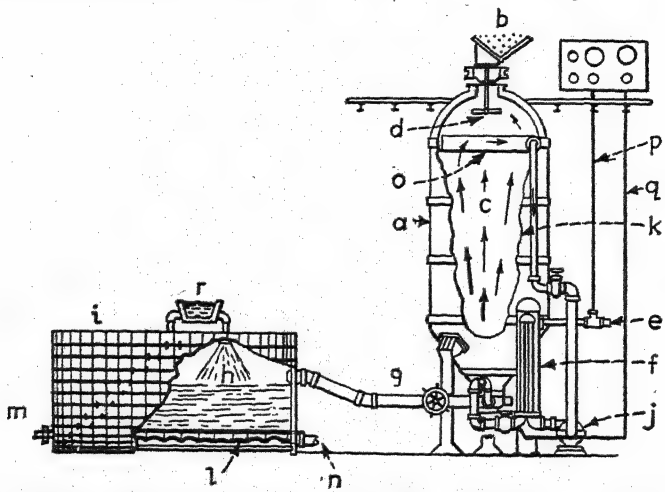

FIG. 49.—Digester and blow pit. *a.* Digester. *b.* Chip bin. *c.* Chips. *d.* Chip distributor. *e.* Steam inlet. *f.* Heater. *g.* Blow-off valve. *h.* Pulp. *i.* Blow pit. *j.* Circulating pump. *k.* Cooking liquor. *l.* Perforated tile. *m.* Pulp outlet. *n.* Water outlet. *o.* Strainer. *p.* Steam control. *q.* Temperature control. *r.* Water. (*Courtesy of Hammermill Paper Co.*)

Chemical Wood Pulp.—Chemical wood pulp is produced by cooking wood chips under pressure in some form of chemical solution that dissolves the lignin and other intercellular materials and leaves the practically pure fibrous cellulose free (Fig. 49.) There are three general processes in chemical wood-pulp production: the sulphite, the soda, and the sulphate. The differences are determined largely by the kind of wood used,

and the quality of paper desired. The sulphite process is the one used most extensively, especially for newsprint, and the chief wood chosen is spruce, which is composed of a little more than half lignin and other nonfibrous materials, the remainder being practically pure cellulose.

In the sulphate process the wood is barked and reduced to small chips. It is then cooked in a digester in a solution of sodium sulphide and caustic soda under a steam pressure of about eighty pounds for eight hours. The ligneous and other soluble matter dissolves away, leaving the pure cellulose free. Sulphate papers have extra strength and are extensively used for wrappings, bags, and other purposes where this quality is of special value.

The soda-pulp process is used largely for pulping hardwoods. It differs from the sulphite process mainly in that sodium hydroxide is used for the cooking agent. Soda-pulp paper holds loading well and is easily coated, which gives it firmness, opacity, and a smooth surface well suited for the manufacture of books, magazines, covers, lithographs, and writing papers. It is highly absorbent and is used extensively for blotting paper, towels, and other absorbent articles. The sulphate process is comparatively new in this country, although it has been in use for many years in Europe. It is a modification of the soda process in which the active ingredient in the cooking liquor is a mixture of caustic soda and sodium sulphate.

Bleaching, Beating, Sizing, and Loading.—After the pulp has been made, it must be treated in various

ways before it goes to the paper machine. In the case of newsprint, bleaching the pulp is generally unnecessary. As a rule it is screened and mixed—about 80 per cent groundwood and 20 per cent sulphite pulp—in special mixers where fillers, sizing, and colors are added as may be required. In the higher grades, however, especially in the whites, bleaching is a necessary part of the preliminary treatment. This is carried on in the beating engine, or in a special bleaching chest.

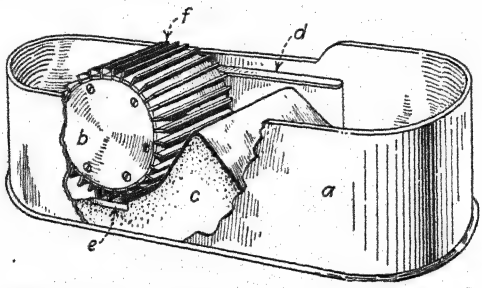

FIG. 50.—Pulp-beating engine. *a*. Tank. *b*. Roll. *c*. Backfall. *d*. Midfeather. *e*. Bed knives. *f*. Roll knives.

Bleaching agents are chemical solutions and are selected to meet the requirements for the different kinds of pulp desired.

A typical beating engine consists of a large, horizontal, elliptical tank about 2 feet deep at one end and 2½ feet deep at the other. A drum having blades on its surface revolves in one side of this tank against a concave bedplate also equipped with blades (Fig. 50). The pulp passes between these blades and is not only thoroughly mixed but is also cut, softened, and frayed out, being better prepared for matting or felting in the paper machine. In this process also the paper is

loaded; that is, the fillers, sizing, and colors are added and mixed. The fillers most commonly used are kaolin or other forms of refined clay, talc, and lime. The sizing is generally prepared rosin, although alum, starch, silicate of soda (water glass), soap, casein, gelatin, and other substances are used. Coloring materials are aniline dyes or other well-known coloring compounds.

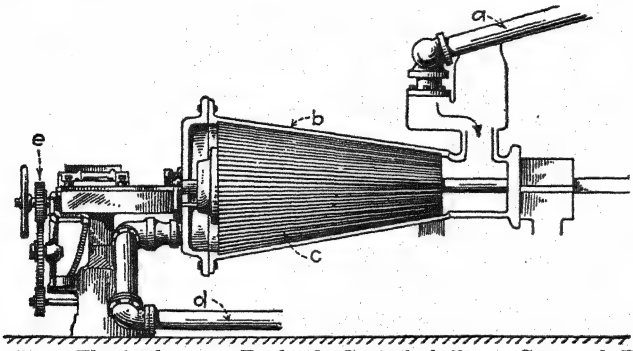

FIG. 50*a*.—The jordan. *a*. Feed. *b*. Conical shell. *c*. Cone. *d*. Pulp discharge. *e*. Adjusting mechanics.

In recent years the "jordan," a conical engine, has largely taken the place of the older types of beating engines especially for newsprint.

This machine consists in the main of a hollow cone shell supplied with blades on its inner surface similar to those of the beating engine. Within this shell revolves a solid cone with blades on its outer surface (Fig. 50*a*). The pulp is introduced into the smaller end of the machine and is disintegrated and refined as it passes between the blades to the larger end, where it is discharged.

Paper-making Machines.—There are two types of paper-making machines in use, of which the Fourdrinier is the most important. A brief description of this machine and the processes involved in making news-print will suffice. A large Fourdrinier machine is a huge rectangular structure sometimes 250 feet long and 20 feet wide consisting mainly of a series of screens, belts, suction boxes, and rolls which spread, form, press, dry, and finish the paper as the sheet passes along (Fig. 50*b*). The pulp, suspended in about 99 per cent of water, flows from the head box over a belt of fine wire mesh which allows the water to drain through, leaving a mat of wet pulp behind. This mat is delivered to another belt, or "blanket," of woolen cloth which passes with its load through a series of wringer rolls which press more water out and leave a sheet of crude paper strong enough to continue the process without the support of the blanket but still containing about 70 per cent of water. The sheet next passes over and under a long series of driers—large, hollow, steam-heated, revolving cylinders, sometimes as many as forty-eight, which dry out the moisture and render the paper "air" dry. As a final stage the sheet passes through a calender, another series of rolls which give final tone and finish to the surface. The paper is finally wound into a large roll and is ready for wrapping and shipment, or in case sheets are required it is unwound into a rewinder and slit into sheet widths required.

Fuel for drying in the larger machines is one of the chief items of cost. About one ton of coal is required

to dry one ton of paper. When it is considered how rapidly these machines run, it is not difficult to imagine that a large amount of fuel for drying is necessary. In the large machines the average speed is about 1,400 feet of paper per minute, or about 16 miles per hour, which means that from the time the pulp leaves the flow box until the paper is wound on to the finished roll, about 11 seconds are consumed, and of this only 6½ are allowed for drying.

Some of our larger paper companies own and control their own timber lands and are practicing modern methods of forestry. In Canada the provinces lease their Crown timberlands to paper companies, which secure the right to cut the wood under certain conservative regulations.

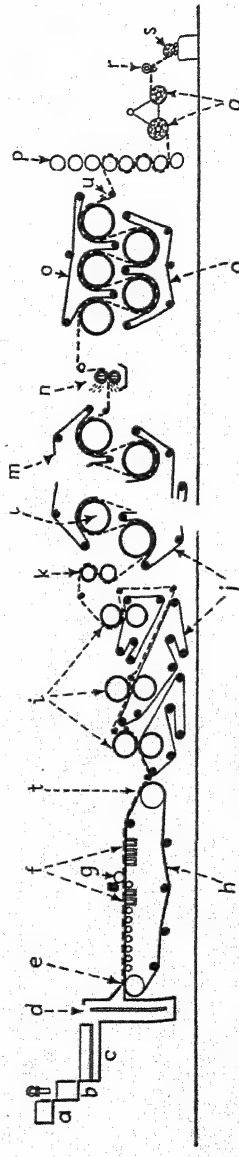

FIG. 50b.—Fourdrinier paper-making machine. *a.* Stuffing box. *b.* Mixing box. *c.* Screens. *d.* Head. *e.* Stock inlet. *f.* Suction boxes. *g.* Dandy roll. *h.* Fine-mesh bronze screen belt. *i.* Press rolls. *j.* Felt blankets. *k.* Smoothing rolls. *l.* Steam-heated dryer rolls. *m.* Felt blanket. *n.* Sizing-solution spray. *o.* Felt blankets. *p.* Calender rolls. *q.* Paper reels. *r.* Slitter. *s.* Paper winders. *t.* Suction roll. *u.* Moisture control. (*Courtesy of Hammermill Paper Co.*)

At the present time a considerable percentage of pulpwood is imported from Canada. But our own supply is still large. In the Northeast, the principal paper-producing states are Maine, New Hampshire, Vermont, and New York. Alaska is one of our largest pulpwood regions, but its distance and the consequent high cost of transportation preclude the development of the industry in those parts for some years to come. Next in order of supply are our Northwestern states, where the stands of Sitka spruce, hemlock, and fir are large and well adapted for the purpose. The pulpwood industry is also developing in the pine section of our Southern states and promises to be of even greater importance as bleaching the fibers becomes increasingly practicable.

Cellophane.—"Cellophane" is the trade name for a paperlike material produced from the purified pulp of wood or cotton (cellulose). It is produced by chemical reaction on the pulp which is afterward rolled into sheets, dried, and cut into size for use.

Because of its transparent, moisture-proof, and sanitary qualities it is valuable for wrappings for foodstuffs, medicines, novelties, and other goods. It is also used for surgical appliances and in linings for balloons and zeppelins.

Vulcanized Fiber.—Another fibrous pulp product somewhat related to paper is known in the trade as "vulcanized fiber." It is produced by saturating sheets of non-sized high-grade paper in zinc chloride and pressing them together between heated rolls or in a heated platen press. Phenolic resins are also being

used for bonding materials. After pressing, the material is thoroughly washed to remove all surplus zinc

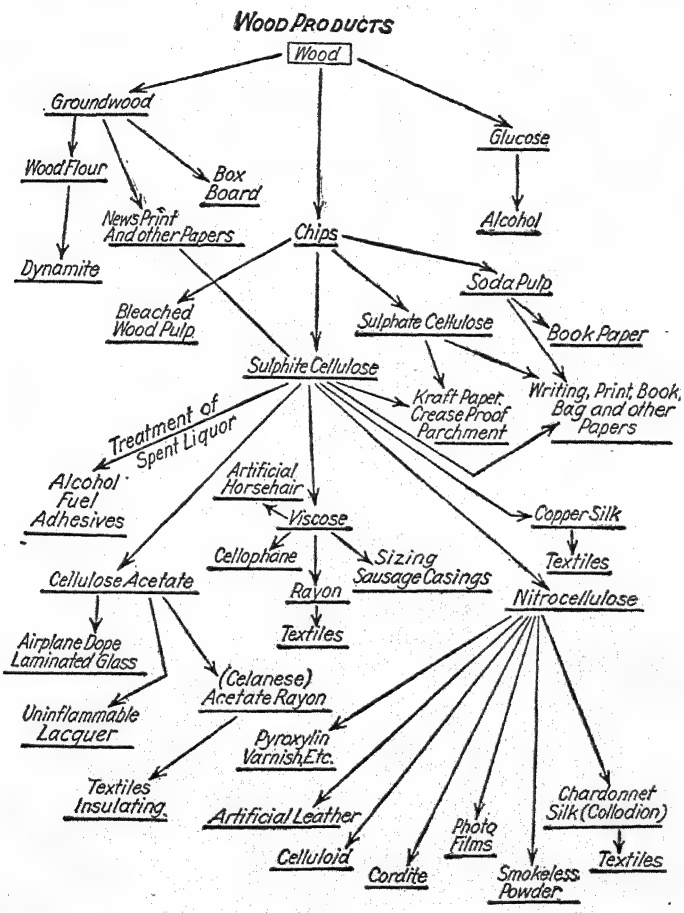

FIG. 51.

chloride. Sheets up to one-eighth of an inch in thickness are run over large steam-heated drums for drying similar to those used in a paper machine. For

materials over one-eighth of an inch in thickness the saturated paper is wound on to heated drums until the desired thickness is obtained. It is then cut and peeled off, washed and dried in a hot oven, and then flattened and pressed in a powerful platen press. Surface finish on both kinds of fiber is obtained by passing the sheets through heavy calender rolls.

Vulcanized fiber has many commercial uses; among the more common are electrical insulation, tool handles, shipping tags, waste baskets, textile bobbins, trunks, and cases.

Paper Terms

beating engine—An engine for refining and hydrating fibers.

caustic soda—A chemical obtained by the electrolysis of brine.

cellulose—The fibrous material or framework of which plants are composed.

chemical pulp—Pulp obtained by separating the fibers of wood by dissolving the gums, rosins, etc., surrounding them with a chemical solution.

digester—A steel cylinder in which wood is cooked in chemicals under pressure to obtain pulp.

groundwood—Pulp produced by grinding or tearing the wood fibers apart on a grindstone.

flow box—The container at the receiving end of a paper machine that contains and feeds the pulp to the machine.

head box—See Flow box.

jordan—A special conical engine for refining and hydrating fibers.

lignin—The intercellular matter in woody plants.

loading material—Any material, as clay, introduced in paper to give it body or firmness.

mechanical pulp—See Groundwood.

newsprint—Paper used for newspaper work, produced principally from wood pulp.

sizing—Any material, as gelatin or rosin, introduced in paper to give it body and finish.

slush—Groundwood mixed with water as it comes from the grinders.

soda process—The process of producing wood pulp by cooking wood chips under pressure in an aqueous solution of sodium hydroxide.

stuff—Pulp prepared for paper.

sulphate process—The process of producing wood pulp by cooking wood chips under pressure in an aqueous solution of caustic soda and sodium sulphide.

sulphite process—The process of producing wood pulp by cooking wood chips under pressure in a solution of sulphur dioxide, in an aqueous solution of calcium bisulphite, or a mixture of calcium and magnesium bisulphite.

Paper Questions

Group I

1. Give a definition of paper.

2. What are some of the first records that we have of paper making? What material was used?

3. What Eastern city early became famous for paper making? Why did the industry develop there?

4. By whom were rags first used for paper?

5. When and under what conditions was paper making introduced into Europe?

6. What can you say about early paper making in Holland?

7. By whom and about what time was the first paper mill established in England?

8. When, where, and by whom was paper making started in America?

9. Who was Nicholas-Louis Robert, and what contribution did he make to the paper industry? How did Robert's invention compare in production to a modern large Fourdrinier machine?

10. Why, by whom, and about what year was wood substituted for rags in making paper?

11. Where did the Fourdrinier paper machine get its name?

12. What are the four general steps in modern paper making?

13. Name several kinds of materials from which paper is made.

14. What kind of wood is used most extensively for newspaper?

15. Name the two general processes of pulp production.

16. Name the three general divisions of the chemical process, give the principle involved in it, and mention the general characteristics of the paper produced in each division.

17. About what percentage of groundwood is used for newspaper stock?

GROUP II

18. What special characteristic does wood have that makes it good for paper making?

19. Why should wood be barked before being ground into pulp?

20. In what way did the spread of education help the paper industry?

21. What is meant by newsprint?

22. Name qualities that writing paper must possess that are not necessary for kraft paper, and vice versa.

23. In what general respect should paper for cement sacks differ from that used in this book?

24. What special quality must paper towels possess?

25. Why is it difficult to write with ink on newspapers?

26. How does blotting paper differ from writing paper?

27. Why did the Arabs wish to keep paper making a secret?

28. Give reasons why we find large paper mills in Maine.

29. Give reasons why we find a large paper mill at Niagara Falls.

CHARCOAL

Charcoal is the charred remains of wood heated in the absence of air, and it is nearly pure carbon.

Early Importance.—In the early history of our country the charcoal industry was of special importance because this commodity was the universal fuel

used for smelting iron ore. Because of this fact the center of the iron industry was obliged to move several times to keep in touch with the receding forests. About the middle of the past century, however, the successful use of coal and coke in smelting was accomplished, and the whole iron industry was revolutionized. Charcoal no longer played an important part as a smelting fuel except in localities where it was very cheap or where a very superior grade of iron was required. (Charcoal-smelted iron is still the highest quality of iron produced.)

Methods of Burning.—Large quantities of charcoal are obtained as a by-product of the wood-distillation industry, although in a few instances the old-fashioned charcoal pit may still be seen in operation, especially in foreign countries. A typical pit of this kind consists simply of a level place in the ground from 20 to 40 feet in diameter. In this pit, billets of wood 2 or 3 feet long are stacked roughly in the form of a dome and covered with leaves and earth to keep out the air (Fig. 52). A vertical hole or flue is left in the center in which to start the fire and to facilitate burning. After the fire is lighted, the wood burns slowly outward until the edge is reached, when the burning process is complete.

The pit is allowed to cool, and the charcoal is removed and is ready to be shipped. The time required for burning in the larger pits is from 20 to 30 days depending upon the kind and condition of the wood used, the weather, and the care exercised in stacking. The amount of charcoal obtained from

a typical burning varies with the different kinds of wood. Dry chestnut will produce about 40 bushels per cord, shellbark hickory about 35 bushels, and beech only about 22 bushels.

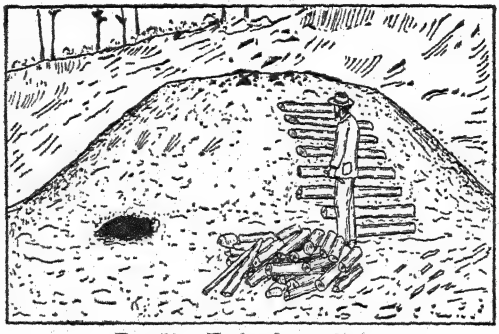

FIG. 52.—Early charcoal pit.

General Uses.—Large quantities of charcoal are still used for refining copper and other metallurgical work, where it is sought not only for its heat-producing

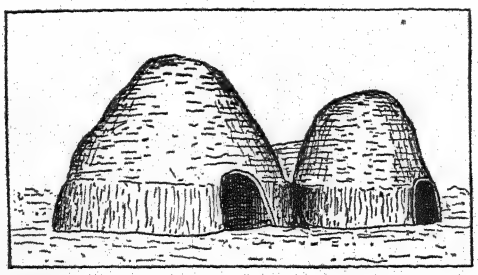

FIG. 53.—Brick charcoal ovens. (*After Spring.*)

qualities but also for its reducing (carbonizing) effect. Other uses are for filtering, in the arts, for making explosives, for medicine, for domestic fuel, and as an absorbent.

In parts of Spain, Italy, and France, as well as in some other European countries, charcoal is still the main source of fuel for domestic use. It is cheaper in these sections to burn the wood into charcoal in the forests and ship the commodity to the consumer than it is to transport the wood before burning.

Charcoal Terms

billets—Pieces of wood of convenient size for handling in a charcoal pit.

carbon—A non-metallic element found in all organic substances. The heating element in charcoal and coal.

charcoal pit—A flat, level place, generally round, in which the billets of wood are piled for burning into charcoal.

cord of wood—A pile of wood 4 feet wide, 4 feet high, and 8 feet long: 128 cubic feet.

Charcoal Questions

Group I

1. What is charcoal?

2. What was the principal use of charcoal in former years?

3. What fuel has largely taken the place of charcoal for metallurgical work?

4. What industry has largely taken the place of charcoal burning in pits?

5. Name the principal uses for charcoal at the present time.

6. Why is charcoal used for domestic fuel in Europe more extensively than in the United States?

7. Upon what does the yield of charcoal per cord of wood depend?

8. Name some of the best woods for charcoal production.

Group II

9. Why must practically all air be excluded from a charcoal pit?

10. How did the vanishing forests affect the early iron industry?

11. What element in charcoal makes it valuable for metallurgical work?

12. Why is charcoal burning in pits wasteful?

WOOD DISTILLATION

Although the production of charcoal has been carried on from very early times, the practice of saving the gaseous vapors driven off in the process is of comparatively recent date. The process used for this purpose is known as "wood distillation" and consists of two general branches, hardwood distillation and

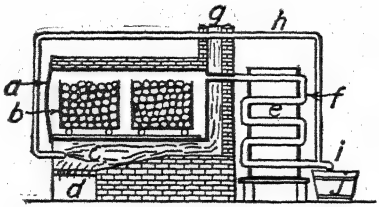

FIG. 54.—Wood-distillation apparatus. *a.* Retort. *b.* Cars of wood. *c.* Furnace. *d.* Ash pit. *e.* Condensing tank. *f.* Worm. *g.* Stack or chimney. *h.* Non-condensable gas pipe. *i.* Tail pipe. *j.* Collecting tub.

softwood distillation, the object being to recover pyroligneous acid, tar, wood creosote, turpentine, and other useful distillates that had heretofore gone to waste.

Hardwood Distillation.—Hardwood distillation, as the name implies, uses hardwoods for its raw material. The first plant for the industry in this country was established near Binghamton, N. Y., about the middle of the past century, more especially for the purpose of producing acetate of lime, which found a ready market in the textile industry. The charcoal and wood-tar by-products were generally burned in the furnaces, as

there was very little market for these commodities. The apparatus for this plant was brought over from Scotland, and a number of expert workmen were also imported to direct its operation. So profitable did the venture prove that other plants soon sprang up in southern New York and Pennsylvania. The industry has gradually developed, and at the present time it is found quite extensively in Michigan, New York, Pennsylvania, Tennessee, and other states in the regions where second-growth hardwoods are abundant.

Equipment and Operation.—A typical hardwood distillation plant consists in general of a retort house, storage yards, trackage and cars, a still house, cooling ovens, a charcoal house, and other equipment necessary for handling wood and caring for the finished products.

A typical unit retort consists of a rectangular steel shell about 7 feet high, 8 feet wide, and from 25 to 50 feet long. It is supplied with tracks for operating the cars, air-tight doors, an opening for conveying away the vapors, and a fire box underneath (Fig. 54). Each retort is connected with a condensing system consisting of a copper worm immersed in a tank of water. A pipe leads from a trap in the tail pipe to convey the non-condensable gases back to the furnace. Steel cars holding about two cords of wood each are used for charging; the fuel can be wood, gas, oil, or coal and is governed largely by the proximity of the plant to the particular source of supply.

After the ovens are charged, the doors are closed and sealed to keep out the air. The temperature

is then gradually raised until it has reached about 600°F., the process requiring about twenty-four hours. During this time the gaseous vapors (volatile matter) are driven off and passed through the worm and are condensed while the charcoal (nearly pure carbon) remains in the retort. The major distillates are pyroligneous acid and tar, with a certain amount of non-condensable gas which is used in the furnace for

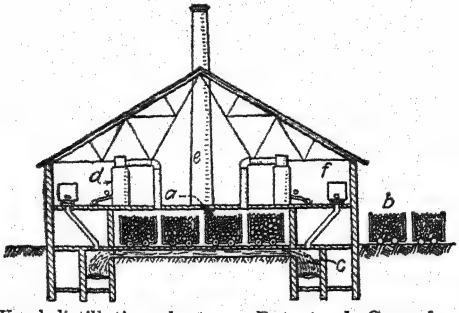

FIG. 55.—Wood-distillation plant. *a*. Retort. *b*. Cars of wood. *c*. Furnace. *d*. Condenser. *e*. Stack. *f*. Fuel car. (*After Thorp.*)

fuel. The quantity of distillates obtained depends upon the kind and nature of the wood used and the care with which the operations are carried on. Pyroligneous acid is redistilled and treated to obtain wood alcohol, acetate of lime, and other chemicals. The tar is also sometimes redistilled for wood-creosote oil and other products. The charcoal is slowly cooled in special cooling ovens and is ready for the market.

Hard maple is considered the best kind of wood for both the quantity of production and the quality of the distillate. Next in relative values are beech, birch, ash, oak, and hickory, although their values may vary somewhat in different parts of the country and under

different conditions. Hardwood distillation is no longer so relatively important, since many of the chemicals formerly its monopoly, as alcohol, acetol, and acetic acid, are now manufactured in large quantities by synthetic methods.

Softwood Distillation.—Softwood distillation uses soft woods for its raw material, especially the long-leaf pine of the Southern states, although other species, as the short-leaf pine, Cuban pine, and Douglas fir, are used to a limited extent.

The industry is carried on mostly in the South Atlantic and Gulf states because of the abundance of pine stumps, pine mill refuse, and other waste pine-wood found in these sections.

Equipment and Operation.—There are on the market several types of softwood distillation apparatus involving both horizontal and vertical retorts. Typical horizontal retorts are practically the same in principle as those used for hardwood distillation, except that they are smaller and are generally charged by hand instead of with cars. In the main they consist of iron or steel shells of one to four cords capacity. They are fitted with air-tight doors, fire boxes for heating, and openings for leading away the gaseous vapors and suitable condensing systems very similar to those of the hardwood process.

The principal products are turpentine, pine tar, pine oil, wood creosote, and charcoal. The uses of turpentine and rosin are discussed under another topic. Pine tar finds a market for heavy oils, for medicine, for soap, for paints and stains, for cordage, for a

disinfectant, for insulating, and for other purposes. Pine oils are used in the flotation process of concentrating ores, as a solvent, as a disinfectant, for paints and varnishes, and for other purposes. From the major products, several refined distillates are obtained, such as dipentene, pine-tar oil, solventene, pine-o-sote, solvo, and others, each having its special use in the arts or in industries.

Softwood Distillation by Steam.—In recent years a process of softwood distillation by steam under pressure has been developed that has a promising outlook. The main object of this process is to produce turpentine, rosin, and pine oil from stumps, mill refuse, and other odd pieces of resinous woods now going to waste. The process is described under wood turpentine.

Wood-distillation Terms

acetate of lime—The residue obtained when distilling pyroligneous acid treated with lime to obtain wood alcohol.

by-product—An additional or side product obtained in the manufacture of another or main product.

condensable gas—Any gas that can be condensed into a liquid.

cooling oven—A large rectangular steel oven in which the charcoal obtained from the wood-distillation retort is cooled.

distillate—A liquid obtained by condensing a vapor.

distillation—The process of driving off the vapors from any material and condensing them into liquids.

destructive distillation—Distillation in which the original form of the material is destroyed.

gaseous vapors—A combination of gas and vapor driven off from a material by heating.

hogging—Reducing wood to small chips in a chopping machine called a "hog."

non-condensable gas—A gas that will not condense into a liquid.

oven retort—The steel container in which the wood is heated in the absence of air to drive off the vapors.

pine oil—A heavy oil obtained in the process of distilling pinewood.

pyroligneous acid—An astringent, reddish liquid, the primary distillate obtained in distilling hardwood.

redistill—Distilling a distillate.

resinous wood—Wood that contains resinous gums, as pine and spruce.

rosin—The residue left in the retort in the distillation of pinewood.

second-growth wood—Wood from trees that have grown on areas from which the original forests have been cut.

wood alcohol—A light, volatile, inflammable liquid obtained by the distillation of treated pyroligneous acid.

wood distillate—Any liquid obtained from the distillation of wood.

wood gas—A non-condensable gas obtained in the distillation of wood.

wood tar—A black, oily residue obtained in the process of wood distillation.

Wood-distillation Questions

Group I

1. Name the two main branches of wood distillation.

2. What is meant by the terms "condensable" and "non-condensable" gases?

3. Name the kinds of wood used most extensively in the two branches of wood distillation.

4. Name the principal products of both hardwood and softwood distillations.

5. How is wood alcohol obtained?

6. Where were the first wood-distillation plants in this country located?

7. From what country was the apparatus for these plants obtained?

8. Why is the non-condensable gas burned in the furnace?

9. In steam distillation why is the wood generally reduced to fine chips?

10. What is the general yield of products of a cord of fat stump wood?

11. How is rosin recovered in wood distillation?

12. In what noticeable way does wood turpentine differ from gum turpentine?

Group II

13. What is meant by wood distillation? What is meant by a unit retort?

14. Why are ovens for cooling the charcoal neces ary in a wood-distillation plant? Why must the cooling ovens be air-tight?

15. What would determine the length of the condensing worm?

16. In what parts of the country are we apt to find wood-distillation plants for hardwood; for softwood?

17. What is the meaning of the term "pyroligneous acid"?

18. In what way is the wood-distillation industry connected with the iron and steel industry?

19. What is acetate of lime? How is it obtained? What is its principal use?

TURPENTINE

Historical.—The manufacture of commercial turpentine in North Carolina began as early as 1783. Pitch and tar for naval stores had been produced in some of the Colonies and shipped to England many years before this.[1] There was a great demand for these commodities for ship building, but practically no market for turpentine and rosin, in consequence of

[1] The first shipment of "Hard pitche, tare, turpentyne and rosin" seems to have been made from Virginia in 1608.

which very little attention was given to their production. As late as 1820 rosin dropped as low as twenty-five cents per barrel, a price that would not pay for handling. The increasing demand for turpentine, however, for paints and varnishes as well as for an illuminant and a solvent for rubber gradually stimulated that branch of the industry. But the market for rosin did not keep pace with that of turpentine, with the result that large quantities of the former were thrown out on the dump. In recent years, however, the increasing demand for rosin for a variety of uses has made it profitable to seek out old abandoned still sites and mine the rosin once thrown away as useless.

Prior to 1834, crude-iron retorts were practically the only apparatus used for turpentine distillation. These were not only wasteful but also produced an inferior article. In that year copper stills were introduced which, with the exception of a few minor details, were the same as those used at the present time.

In 1860 the naval-stores industry was the most important of those in our Southern states. During the Civil War, however, it practically stopped but was among the first to revive after the war was over. Since about 1870 there has been a steady growth, and the United States has furnished over 60 per cent of the world's supply of naval stores.

Sources of Crude Gum.—The principal source of raw turpentine gum is the long-leaf yellow pine, although considerable quantities are secured from slash, Cuban, and other pines. Long-leaf pine is

found mostly in a region extending from Virginia into eastern Texas including North Carolina, South Carolina, Georgia, Florida, and parts of Alabama, Mississippi, Louisiana, and Texas (Fig. 56). Formerly South Carolina led all other states in production, but at the present time this state supplies less than

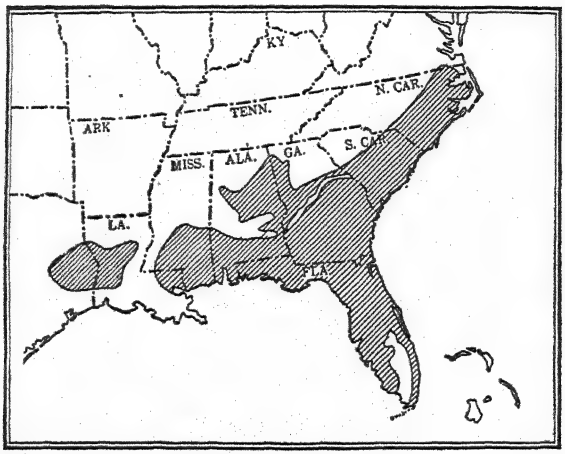

FIG. 56.—Long-leaf, or turpentine, pine region. (*Courtesy of U. S. Forestry Service.*)

1 per cent. At present Florida stands first with Georgia coming next.

Tapping the Trees.—There are several methods of securing the gum from the trees. The older and more wasteful one is known as the "boxing method" and consists of chopping a deep cavity, or box, into the base of the tree near the ground; into this the gum collects (Fig. 57). A small surface is cleared of bark and of a thin layer of sapwood just above the box, known as the "face," out of which the gum exudes. About once a week during the flowing season (March

to November) the face is chipped, or scarified; that is, another thin portion of sapwood is cut away to open up the pores and allow the gum to flow freely. When

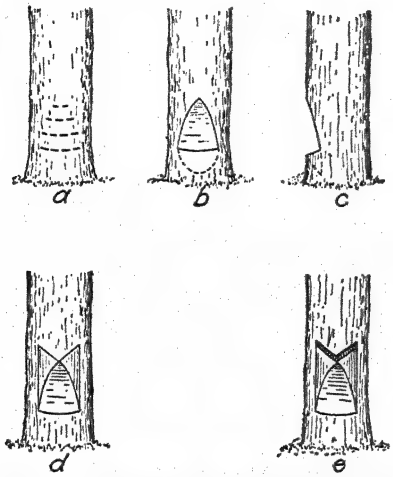

FIG. 57.—Box method of tapping pine trees for crude gum for turpentine (earlier method). (*Courtesy of U. S. Forestry Service.*)

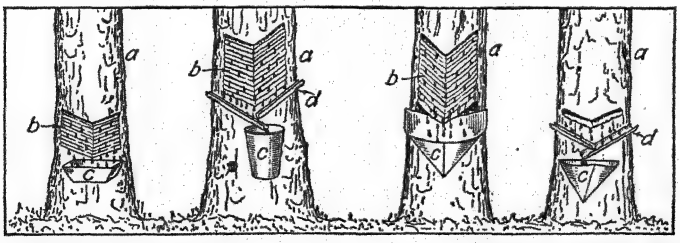

FIG. 58.—Cup-and-gutter and other modern methods of tapping pine trees for crude gum for turpentine. *a.* Tree. *b.* Scarified face. *c.* Cups. *d.* Gutters. (*Courtesy of U. S. Forestry Service.*)

the trees are tapped in the following season, a new face is cut just above the old one. The process is repeated for five or six years, and then the tree as a rule no longer produces gum in paying quantities.

The boxing practice is not only wasteful but also tends to weaken and stunt the growth of the trees. In spite of this, however, it was the only method used in turpentine orcharding in the United States for many years. Like all other deep-seated customs it was hard to break away from. Producers either did not feel able to adopt new methods or were not convinced that any new-fangled idea would produce larger profits. So abundant did the supply of trees seem to be that nobody thought it would ever become exhausted.

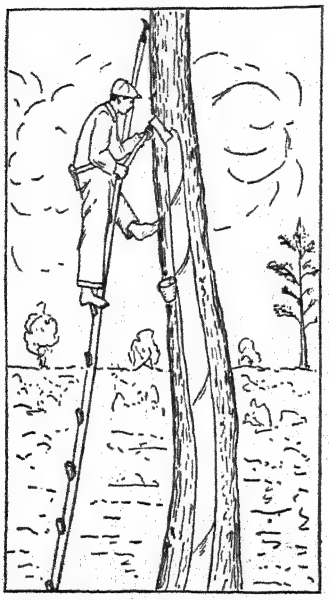

FIG. 59.—French method of collecting crude gum for turpentine. (*Courtesy of U. S. Forestry Service.*)

At the beginning of the present century, however, new and more conservative methods of collecting crude gum began to be developed. Among the most successful of these are what are known as the "cup-and-gutter" method, the "cup-and-apron" method, and the "single-cup" method. In the cup-and-gutter method a face is made on the tree, but without the deep cavity, or box. Two galvanized-iron gutters are inserted into the cuts at the bottom of the face in the form of a wide V. These are so arranged that one empties into the other which in

turn delivers the gum into a cup attached below (Fig. 58). In the cup-and-apron method an oblong, galvanized-iron cup is attached to the bottom edge of the face. The gum is led into this cup by a galvanized-iron apron with one edge inserted into the tree (Fig. 58). In the third method the cup is constructed with a projection on one edge which is inserted into the tree and takes the place of the apron (Fig. 58). All of these methods have proved successful and are extensively

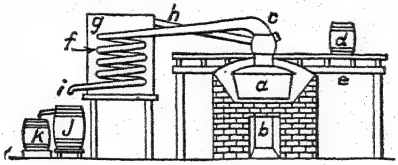

FIG. 60.—Turpentine still. *a.* Kettle, or boiler. *b.* Furnace. *c.* Gooseneck. *d.* Barrel of crude gum. *e.* Charging platform. *f.* Worm. *g.* Cooling or condensing tank. *h.* Water-feed pipe. *i.* Tail pipe. *j.* Collecting barrel. *k.* Turpentine barrel. (*Courtesy of U. S. Forestry Service.*)

used. The cups fill about once every three or four weeks.

Distilling.—The gum is generally collected and transported in barrels to the stills, which as a rule are located on the premises. A typical still consists of a copper kettle of from 500 to 1,000 gallons capacity mounted over a furnace (Fig. 60). A gooseneck leads from the top of the kettle and connects with a spout which in turn is connected with a condensing worm immersed in a tank of water. A large separating barrel is installed at the end of the worm under the tail pipe, and next to this a smaller barrel is placed for receiving the turpentine. A platform is constructed near the top of the kettle for convenience in

charging, and a spout or trough leads from the top of the tank to the top of the kettle to supply water. (Water is added to the charge to prevent the gum from burning and to facilitate the process of vaporizing.) As the charge boils, the vapor rises and passes through the gooseneck to the worm and is condensed

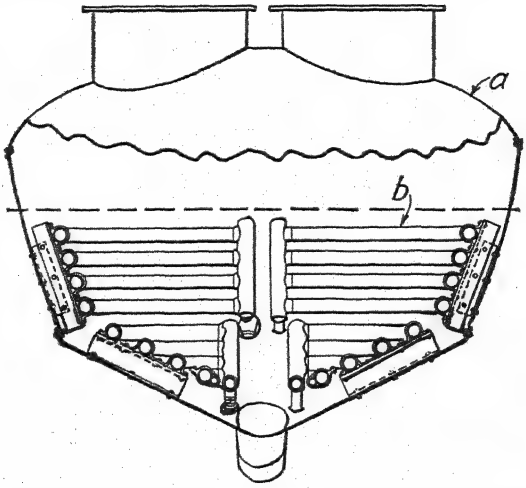

FIG. 61.—Boiler heating unit for steam turpentine still. *a.* Steel shell. *b.* Steam coils. (*Courtesy of U. S. Forestry Service.*)

into a distillate and flows from the tail pipe into the separating barrel.

At the beginning of the operation the distillate is about 45 per cent turpentine and 55 per cent water, but as the process continues, the water boils away until only about 30 per cent remains. This condition is indicated by a peculiar sound in the kettle known as the "call for water." More water is added, and the vaporizing continues until all of the turpentine has passed over. The distillate collects in the sepa-

rating barrel, and the turpentine rises to the top because of its lower specific gravity and can easily be drawn off. The rosin remains in the bottom of the kettle as residue and is removed, strained, and run into containers while still molten, ready for the market. The yield of turpentine from fresh crude gum is from 16 to 25 per cent of the weight of the

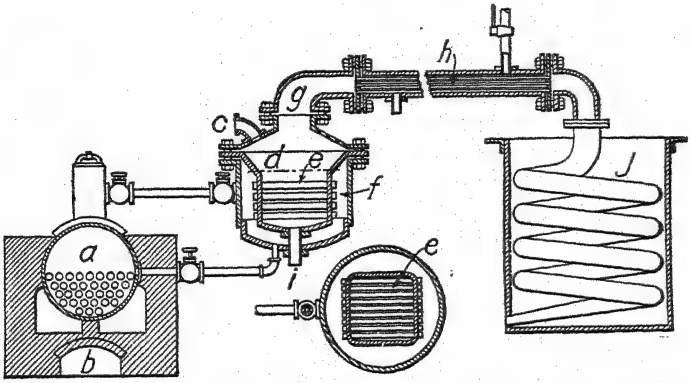

FIG. 62.—French steam turpentine still. *a.* Steam boiler. *b.* Furnace. *c.* Gate valve for charging. *d.* Body of still. *e.* Heating tubes. *f.* Steel jacket. *g.* Still head. *h.* Tubular condenser. *i.* Drain. *j.* Worm. (*Courtesy of U. S. Department of Agriculture.*)

original gum. A kettle has been developed by the United States government using a steam coil for vaporizing instead of direct heat, somewhat similar to the French system (Fig. 62). This aims at cheapening the process and improving the product (Fig. 61).

Grades of Turpentine and Rosin.—At the close of the season there remains on the faces hardened gum that failed to reach the cups. This is known as "scrape" and is removed by scraping. It produces a darker and inferior grade of turpentine than the fresh gum and about half as much in quantity.

Scrape rosin is darker and of inferior grade. The best quality products of both turpentine and rosin are obtained from the early flow of gum from young trees tapped for the first time.

Turpentine is graded as water white, standard, one shade off, two shades off, etc., the last grade

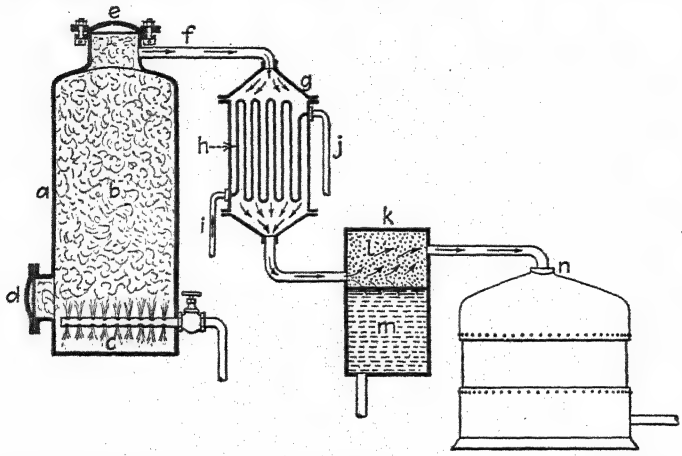

FIG. 63.—Wood-turpentine distillation. *a.* Boiler. *b.* Pinewood chips. *c.* Steam jets. *d.* Chip discharge. *e.* Chip intake. *f.* Vapor pipe. *g.* Condenser. *h.* Coil. *i.* Cold-water pipe. *j.* Water-discharge pipe. *k.* Collecting tank. *l.* Turpentine. *m.* Water. *n.* Turpentine storage tank. (*Courtesy of Hercules Powder Company.*)

being of a decided yellow. Rosin has about a dozen different grades based largely upon its color and purity. After the flowing season is over, the trash is raked back from the base of the trees and burned under control as a precaution against fires and as an aid to improving the pasture for the following season. Under our present method a tract of timber to be worked profitably should contain from 200 to 250 acres and have a stand of 4,000 to 5,000 trees.

Like many others of our industries the production of naval stores has been carried on with little regard for the future supply of raw materials. For the most part the trees have been tapped only about five or six years and then abandoned. Often they have been tapped in a careless manner and have been either killed outright or so weakened that they have been blown down in the first hard windstorm.

Wood Turpentine.—As the supply of long-leaf pine began to show signs of exhaustion, however, attention was turned to devising better methods of tapping live trees, and also to the recovery of gum from stumps, roots, mill waste, and other pinewood waste, of which our Southern states have a large supply. Several processes for extracting the gum from these sources have been developed, among them steam distillation and the use of solvents.

Formerly steam distillation in special apparatus was extensively used. In the process, the wood, after being cleaned, was chipped or hogged into fine pieces about as large as matchsticks and, after being passed under electromagnets to remove any pieces of metal, was distilled in upright containers under steam pressure of about 500 pounds (Fig. 63). During the process, the turpentine and about half of the pine oil and rosin were recovered. The remainder of these products was recovered from the distilled chips by dissolving in a hot solvent and subsequently distilling and refining the liquor. More recently the practice has been first to dissolve the gum from the fresh chips and afterward recover the products by distillation and

chemical refining. The primary products are turpentine, pine oil, and rosin; several secondary products, such as dipentene, synthetic camphor, perfume base, anathol, pinene, vinsol, and others are obtained from the primary products by subsequent distillation and further refining. Turpentine obtained from stumps and other dead wood differs in some respects from that obtained from green trees, but for all practical purposes its uses are the same.

Formerly the spent chips were either thrown out or used for generating steam, but in recent years processes have been developed for converting them into kraft-paper stock, insulating board (temlock), and raw materials for other fiber products. Since the stumps and roots contain the largest amount of fat, they are most profitable for gum production. They are loosened from the ground either by blasting or with huge stump pullers and, after being cleaned of dirt, are transported to the extracting plants. They are obtained from large tracts of land owned by the companies or are purchased outright from smaller land owners living in the vicinity. The industry has two special advantages in that it makes use of a heretofore worthless raw material and at the same time clears the land cheaply for agricultural purposes. In view of the rapidly diminishing supply of long-leaf southern pine trees, the wood-turpentine branch of the naval-stores industry should experience no difficulty in establishing itself on a profitable commercial basis.

The U. S. Forestry Service and other agencies have made experiments in the production of turpen-

tine and rosin from some of our western pines and also from the stumps and deadwood of the exhausted white-pine sections of Michigan and other North-central states, but up to the present time the results have not been of sufficient importance to warrant engaging in the industry on a large commercial scale.

Uses of Turpentine and Rosin.—Turpentine has a large variety of uses. Over 75 per cent of the production goes into the manufacture of paints, varnishes, stains, etc. It is important in the manufacture of cloth print goods as an agent to prevent the colors from running. It is used as a solvent for rubber, as a lubricant, for medicinal purposes, in making synthetic camphor, in fireworks, in printer's ink, in perfumery, in making crayons, and in many other articles too numerous to mention. Petroleum products are being substituted for turpentine in some branches of industry. But as yet nothing has been found to take its place for a large number of important uses.

The most important use of rosin is in the manufacture of soap. This is followed by its use as a glaze for writing paper, also in paints, varnishes, and stains, in leather dressings and polishes, in the manufacture of linoleum and oilcloth, for medicinal purposes, in sealing wax, as a lubricant, and for a variety of other purposes. Pine oil is also used extensively in paints and varnishes. It is especially valuable as a frothing agent in the flotation process of concentrating ores. It also finds important uses in the textile industry and in perfumes, disinfectants, polishes, and cleaning compounds.

Turpentine and Rosin Terms

blaze—A mark on the tree that is to be tapped, generally made with an ax.

boxing—Cutting a deep notch at the base of a tree or collecting the crude gum.

call for water—A peculiar sound in the kettle indicating that more water is needed.

charging platform—A platform near the upper part of the kettle on which the barrels of crude gum are handled.

chipping—Chopping off a small space at the base of a tree to expose a face for flowing of the crude gum.

condensing tank—The tank containing cold water in which the worm is cooled.

crop—The whole quantity of crude gum collected from a given area in one season.

cup-and-gutter method—The method of using the cup and gutter for collecting crude gum.

dipping—Gathering the crude gum from the boxes or cups.

face—The exposed surface of sapwood left by chipping, out of which the crude gum flows.

gooseneck—The curved pipe for the vapor leading from the kettle.

kettle—The vessel or container in which the crude gum is vaporized.

long-leaf pine—A southern pine with long needles, the best kind of tree for turpentine production.

orcharding—Working a given area for crude gum for turpentine.

pitch—The same as crude gum.

resin—The name applied to a gum in a resinous tree.

rosin—The residue left in the kettle after the vapor has passed over. Also called resin.

scarification—Chipping the face to expose new surface to allow the gum to flow freely.

scrape—The dried gum gathered (scraped) from the face after the flowing season is over.

still—Apparatus used for vaporizing a substance and condensing the vapor into a liquid.

stiller—The man who operates the still.

tail pipe—The end of the worm out of which the distillate (turpentine and water) flows.

tapping—Chipping and otherwise fitting the tree for the flow of crude gum.

temlock—The trade name for building insulation board made from wood fiber, especially pinewood.

turpentine orchard—A definite area containing pine trees used for producing turpentine.

vapor—The gaseous material arising from the crude gum when heated.

wood turpentine—Turpentine obtained from distillation of sawdust, roots, and other refuse containing crude gum.

worm—The coil of pipe in the tank in which the vapor is condensed.

Turpentine and Rosin Questions

Group I

1. In what part of the country do we find the turpentine industry?

2. Name the leading states for the production of turpentine.

3. Name the principal kind of tree used for turpentine production.

4. Name other kinds of trees used for turpentine production.

5. Explain two methods of tapping for crude gum for turpentine. Which of these methods is better? Give reasons why.

6. Why is chipping necessary?

7. About how many years can a tree be tapped for crude gum?

8. Give a brief description of the still used for turpentine production.

9. What is the general process of distillation?

10. What is meant by wood turpentine? How is it produced?

11. Name some by-products obtained in the production of wood turpentine.

12. Give important uses of pine oil.

13. Name some important uses of both turpentine and rosin.

14. What is the difference between rosin and resin?

15. What substitute is beginning to take the place of turpentine?

16. Name two special advantages of the wood-turpentine industry.

Group II

17. Why are the chips passed under an electromagnet before being processed?

18. Why is the center of the gum-turpentine industry changing?

19. In what part of the tree trunk is the crude gum found?

20. What other sources do we have for the production of turpentine besides growing trees?

21. Why are other sources beside growing trees for turpentine production becoming more important?

22. Give reasons why the center of the turpentine industry is gradually changing.

23. Why is water for the kettle sometimes taken from the cooling tank?

24. What fuel is likely to be used in gum-turpentine distillation?

25. What is meant by mining rosin?

26. How does water get in with the turpentine in gum distillation?

27. Why is the turpentine industry sometimes called the naval-stores industry?

28. What is the by-product of the gum-turpentine industry?

TANBARK AND LEATHER

The tanning of leather depends largely upon the element obtained from trees and plants known as "tannin," although mineral tanning has come into extensive use in recent years. Many varieties of trees and plants contain this element, but only a few contain sufficient quantities to pay for gathering. The more common sources of tannin are given later (Fig. 68*a*).

SOURCES OF VEGETABLE TANNIN EXTRACT*

From	Found in	From	Found in
Hemlock bark...	United States	Valonia.....	Asia Minor
Oak bark.....	United States	Divi-divi.....	Central America
Chestnut wood..	United States		
Quebracho wood and bark.	Argentina, South America	Mangrove bark..	Tropical forests
		Wattle bark.....	South Africa
Myrobolans.....	India	Gambier.....	Singapore
Sumac bark.....	Sicily		

* Courtesy of American Leather Producers, Inc.

Hemlock, oak, and hickory barks are comparatively little used in modern tanning because of their increas-

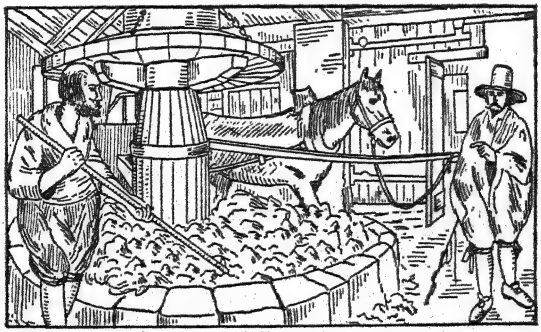

FIG. 64.—Early method of grinding bark for tanning. (*Courtesy of American Leather Producers, Inc.*)

ing scarcity and their higher cost as compared with tannin extracts from other materials.

In the early history of the country large sections of our magnificent forests were wasted in the endeavor to secure bark for tanning. In the Catskill hemlock

belt alone, thousands of trees were felled and stripped of their bark and allowed to lie and rot. But in recent years the bark has become a sort of by-product, since the trees have been cut primarily for their lumber.

Bark Peeling.—Bark peeling is done in this part of the world in the spring, generally from April to July, because during this season bark is loose and slips off easily. A typical peeling crew consists of two log

Fig. 65.—Bark-peeling spud.

buckers, one fitter, and one spudder. Before the trees are felled, a ring of bark about four feet long is peeled from the base as near the ground as possible. The felling is then done by the log buckers, who also trim off the branches and afterward cut the trunks into logs. The fitter now rings and splits the bark about every four feet all the way up the trunk, and the spudder peels the pieces off with a tool called a "spud." (Fig. 65.)

The season of bark peeling is always one of great activity because of the shortness of time in which the peeling can be done. For this reason, the tree trunks are often not sawed into logs until after the rush of the peeling season is over.

Extracting Tannin.—After the bark has dried, it is hauled to the extracting plants or tanneries and ground into small pieces about the size of white beans in a bark mill (Fig. 66) and soaked or leached in vats to obtain the tannin extract (Fig. 67). Spent tanbark is used largely for fuel at the plant; small quantities

are also used in the manufacture of white lead and for other minor purposes.

Tannin is extracted from chestnut and quebracho woods by steeping, or leaching with hot water or hot

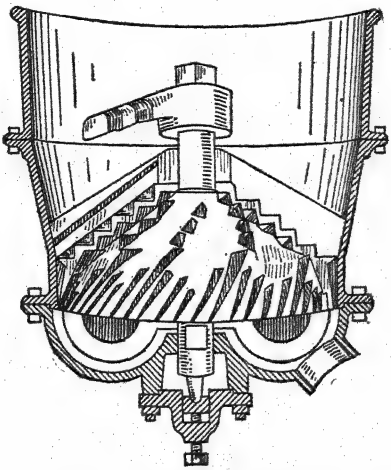

FIG. 66.—Modern tanning. Bark mill. (*Courtesy of G. W. Baker Machine Company.*)

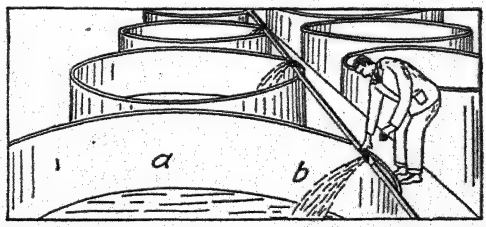

FIG. 67.—Early tanning. Leaching tanbark. *a.* Leach vats. *b.* Water or weak tanning liquor. (*Courtesy of Graton and Knight Company.*)

liquor. The wood is chipped into small pieces and placed in wooden vats. There is generally a series of these vats, and the liquor passes over the chips from one to the next, gaining strength as it moves along. It

is finally drawn off from the tail vat; when it has been filtered and concentrated it is ready for use. The process of obtaining tannin from pods, leaves, etc., is practically the same as for barks. In addition to vegetable tanning materials, mineral salts (especially chromium salts), oils, and dyes are also used.

TANNING

NOTE.—Tanning does not naturally belong under the head of tanbark, but because of their close connection it is inserted here.

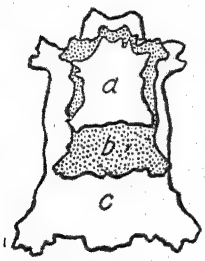

FIG. 68.—Pelts. *a.* Skin. *b.* Kip. *c.* Hide. (*Courtesy of American Leather Producers, Inc.*)

Historical.—It is evident that the skins of animals have played a very important part in clothing and otherwise serving mankind since the beginning of the human race. At first the skins were probably used just as they came from the backs of the animals. But it must have been discovered at an early date that by treating them with the juices of certain plants they became tougher, more pliable, and more durable.

A great many processes of tanning have been in use, and those we know today are the results of centuries of experiment, although up to a comparatively recent date very little attention had been given to putting the industry on a scientific basis. In the early history of the country small tanneries were numerous (Fig. 64). They were located wherever a supply of bark could be obtained and where pelts could be

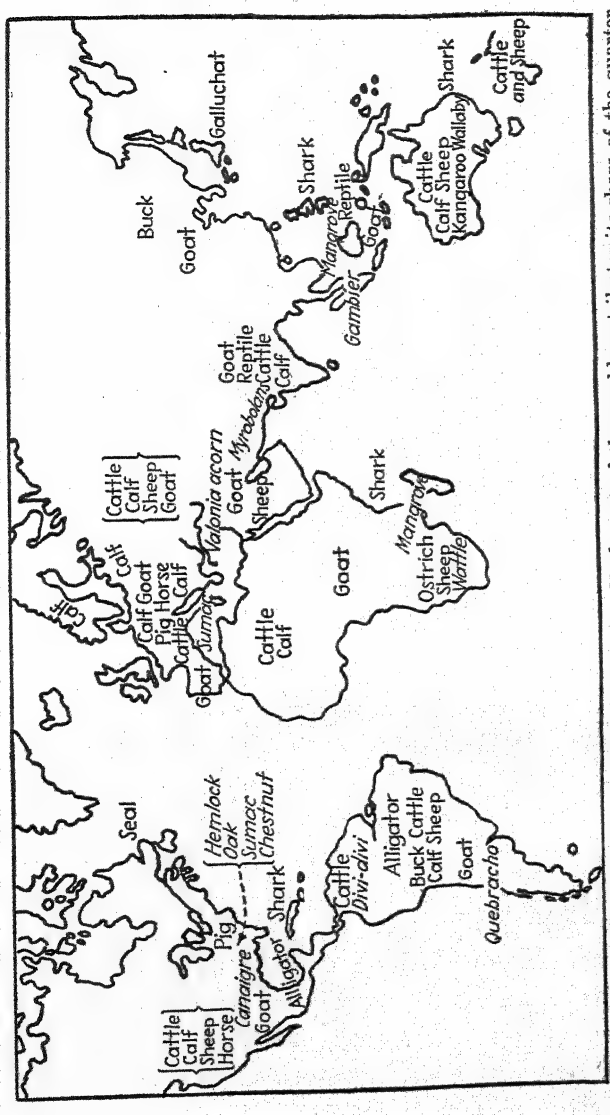

FIG. 68a.—Where hides and skins originate. Each part of the world contributes its share of the quarter million hides and skins imported by United States tanners every working day. This map shows the principal producing regions—and also indicates principal sources of vegetable tanning materials, which are indicated in italics. Chrome for tanning comes mainly from Southern Africa. (*Courtesy of American Leather Producers, Inc.*)

secured in sufficient quantities to pay for tanning. The leather generally went to supply the local demand for shoes, harnesses, saddles, and other useful articles. (The traveling shoemaker and harness maker were personages of great importance in the early days.) But, as the supply of bark began to give out, smaller tanneries were obliged to shut down until the industry has largely become centralized into a few large plants, generally operated in connection with shoe factories or other industries using large quantities of leather for their raw materials.

Sources of Pelts.—In recent years a great deal of attention has been given to the subject of tanning, and consequently the industry has developed along more scientific lines. Raw materials (pelts of animals) are classified as hides, kips, and skins (Fig. 68). Hides from steers, cows, horses, and buffaloes produce heavy leather used for shoe soles, harnesses, saddles, heavy bags, and cases. They are also split and used for shoes and other articles requiring thinner leather. Kips come from the young (about half-grown animals) of the foregoing species and are used for leather for shoe uppers, hand bags, boots, etc.; and skins come from sheep, goats, calves, pigs, kangaroos, and dogs and produce leather for gloves, finer shoe uppers, pocketbooks, and fancy articles. Special leathers are also obtained from alligator and walrus hides, shark skins, snake skins, and other minor sources. At the present time the main supply of heavy hides comes from Argentina and other South American countries and the great central plains of the United States. Of

course, every locality where domestic animals are grown produces pelts of different kinds, but as a rule the quantities are insignificant compared to the supply demanded by the large tanneries.

Tannage of Heavy Hides.—There are three general processes of tanning leather: vegetable tannage, mineral tannage (also mineral and vegetable combined), and oil tannage. Only a brief description of some of the most important phases of these can be

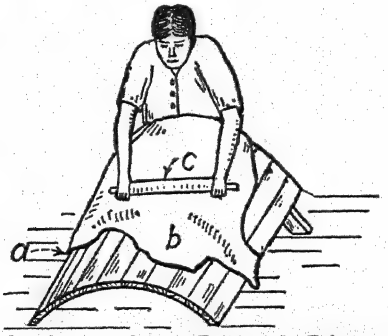

FIG. 69.—Beam hand at work. *a*. Beam. *b*. Pelt. *c*. Fleshing knife.

given in this connection. Heavy hides are generally tanned with the extract from barks or woods. The hides are first soaked in clean water to remove the salt and other dirt and to make them pliable. They are next "fleshed" to remove any scraps of meat that may have clung to them in the process of skinning.

In modern tannage the fleshing is generally done by a special machine supplied with a roller having spiral rows of knives on its surface that remove the pieces of flesh by a scraping action. Formerly fleshing was done entirely by hand, a practice probably followed

in some smaller tanneries today. The hides were thrown hair side downward over a convex, slanting bench called a "beam" (Fig. 69), and the pieces of flesh were shaved off with a long two-handled fleshing knife (Fig. 70) by a workman called a "beamster" or "beamhand." The method is still in use in modern tanneries to remove odds and ends left by the fleshing machine. The hand process requires special skill to avoid cutting holes in the hide or leaving pieces of flesh, either of which would damage the finished

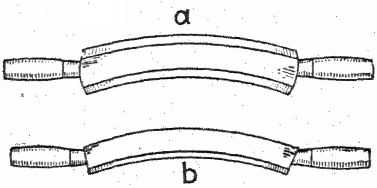

FIG. 70.—Modern tanning. *a*. Fleshing knife. *b*. Dehairing, or fine-hairing knife.

leather. The fleshings are used principally in the manufacture of glue, soap, and fertilizer.

After the hides are cleaned they are soaked in a solution of lime water and chemicals to loosen the hair and are then "dehaired" or "fine-haired," as it is sometimes called, on a machine similar to that used for fleshing and afterwards touched up by hand on a beam with a blunt "fine-hairing" scraping knife (Fig. 70) to remove any hair left by the machine. (Formerly the dehairing was done entirely by hand with the hand dehairing knife. In some instances in modern practice it is dissolved with an acid.) The hair finds a market as a binder for mortar, as a filler for mattresses, for felts, and in upholstery. The hides

are next thoroughly washed, generally in a revolving drum (Fig. 71), and after being "bated"—treated with a solution to remove any traces of lime and to make them soft—are taken to the "rockers" and introduced for the first time to the tanning elements. In the older tanneries a typical set of rockers consisted of a series of vats, each about 8 feet long by 6 feet wide and 5½ feet deep, arranged side by side and so connected

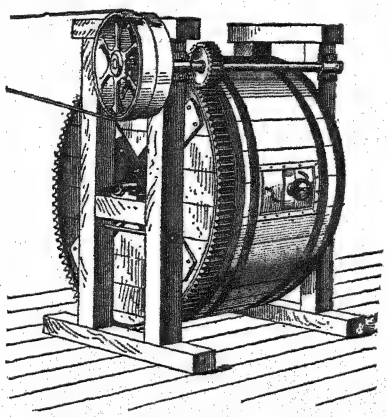

FIG. 71.—Modern tanning. Washing drum. (*Courtesy of G. W. Baker Machine Company.*)

that the liquor from the bottom of one vat flowed into the top of the next and so on through the series. By this arrangement the liquor was constantly changing and becoming weaker as it passed along over the hides until it left the tail vat practically worthless and was either thrown away or sent to the leach vats for reconditioning with fresh bark. The hides were suspended in the rocker vats on frames that had a slow rocking movement, keeping the liquor thoroughly stirred and exposing all parts to the tanning elements

evenly. About fifteen days was required for the rocker process, during which time any traces of lime were removed, and the hides were colored and slightly tanned and were ready to receive the stronger liquor of the "lay-away" vats (Figs. 72 and 73). The "pack," as the batch of hides was now called, was placed in the lay-away vats in strong liquor with fresh-ground tanbark sprinkled on each hide as it was

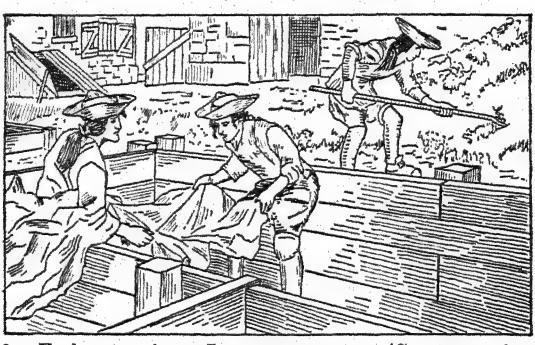

FIG. 72.—Early tanning. Lay-away vats. (*Courtesy of American Leather Producers, Inc.*)

thrown in. The lay-away process required from three to four months, but during that time the pack was hoisted several times and relaid in fresh liquor and bark. When the tannin element had penetrated to all parts, the pack was hoisted for the last time, and the hides (now leather) were cleaned and oiled and hung up to dry. Finally they were moistened and oiled again and rolled out with a brass roller or smoothed on a setting-out machine, which also gave them a glaze, and were ready for market. If hemlock bark was used, the process was known as "hemlock" tan, and the leather was hard and firm, but, if oak

bark was the source of tannin used, the leather was known as "oak" tan and was tougher and more pliable. Often the two elements were combined that produced a medium product known as "union" crop leather and was especially valuable for finer shoe soles.

In modern sole-leather tanning, the hides, after they are cleaned and treated with a bating solution, are tanned largely in the rocker vats, the liquor being

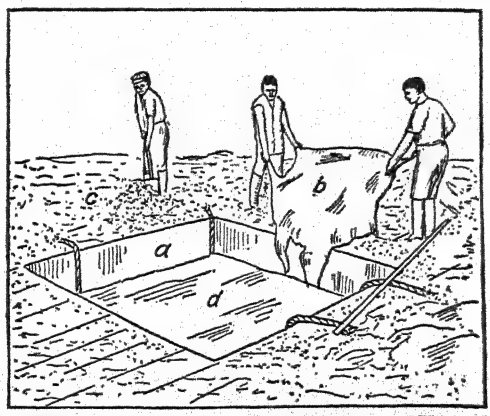

FIG. 73.—Modern tanning. Lay-away vats. *a.* Vat. *b.* Hide. *c.* Ground tanbark. *d.* Tanning liquor. (*Courtesy of Graton and Knight Company.*)

properly graduated and changed to keep the process constant and to produce the desired results in the leather. The time required in the liquor in the modern process for average hides is from seventeen to twenty-four days as compared to three months or more for the older process. The total time required in modern tanning from the beginning of the cleaning processes to the finished leather ranges from thirty-five to forty-five days.

Chrome Tannage.—Chrome tanning is employed for a large variety of leathers used for shoe uppers, gloves, fancy articles, and the like. The processes of cleaning the hides do not differ materially from those used in vegetable tannage, but the actual tanning processes of the two differ in many respects, both as to materials used and methods employed.

The hides, cut in half along the line of the backbone, are split, sliced into thinner pieces, and pickled in a solution of sulphuric acid and salt. (It should be mentioned here that from this point on there are many branches and ramifications in tanning processes too numerous and complicated to be discussed at this time.) The hides are tanned in a special chemical liquor composed of bicromate of soda, glucose, and sulphuric acid, which form chromic oxide, although there are many modifications of this solution, as has been suggested, depending on the kind of pelts used and the nature of the leather required. After the tanning process, the hides, which are now leather, are wrung out on a machine similar to a common clothes wringer and finally passed through various stages of drying, oiling, rolling, smoothing, and staking to render the final leather smooth, even, and pliable and to give it a beautiful finish. Final drying is done by pasting the sides on vertical plate glass or porcelain panels, similar to pasting paper on a wall, to keep them smooth and to prevent them from shrinking.

Natural chrome leather is greenish blue in color. If other shades are desired they are secured by coloring with coal-tar dyes, generally in a revolving drum

before the final finishing processes (Fig. 71). Coloring only on one surface is generally accomplished with a pigment, with a brush, by hand or by a special machine. If alum is added in chrome tanning the leather will be white. The oils generally used are neat's-foot and cod-liver oils. Because vegetable-tanned and chrome-tanned leathers each possess individual qualities, the two processes are often combined and produce a leather superior for shoe soles because of its durability, flexibility, and water resistance.

Oil Tannage.—Oil tanning is used largely in connection with the production of rawhide leather. After the skins are cleaned and dehaired, they are stocked (impregnated) with oil by working them in revolving drums. The leather is very pliable and tough and is used for athletes' shoe lacing, football lacing, machinery-belt lacing, and other articles where these qualities are of special importance.

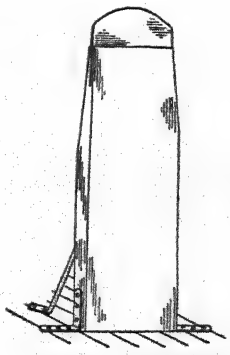

Fig. 74.—Knee-staking stand.

Buckskin.—There are several methods in use in tanning buckskin leather. Among the more common is the "Indian" process, so called because it was used by the American Indians. In general, the process consists in cleaning the skins and tanning them, principally, with the brains of animals. They are finally washed out with soap, dried, and worked out, sometimes over a knee-staking stand (Fig.

74). The leather is tough and pliable and is used largely for better grades of gloves, mittens, and fancy articles. Much so-called "buck" is a suede-finished cattle-side leather on which the grain instead of the flesh has been buffed to raise the nap.

Kid Leather.—Kid leather can be obtained in a variety of ways. A typical process consists in cleaning and liming the skins for from twenty to forty days. After being washed, they are treated with dilute lactic acid (acid of sour milk) in a drum for about an hour and then rinsed. Another process involves the use of alum, salt, flour, and the yolks of eggs. They are finally rinsed and knee-staked out dry and soft.

Snake-skin Leather.—Special fancy leather can be made from snake skins. After the skins are properly cleaned, they are pickled in sulphuric acid and salt. They are then placed in a solution of equal parts of alum and salt for about twelve hours or longer. At the end of this process they are again cleaned and dried and carefully worked out. Snake-skin leather is used to a limited extent for women's fancy shoes, hand bags, and other fancy articles.

Split Leather.—In addition to leather obtained from whole pelts, there is a great deal of so-called "split" leather on the market. This is obtained by splitting thicker leather into thinner sheets on a special splitting machine. Sometimes several sheets can be obtained from the same hide. The grain or top leather is the strongest and most durable of the splits and is used largely for uppers for better grades of shoes and other purposes where higher quality and better finish are required. The other splits are weaker and generally

less attractive in appearance and are used for linings, cheaper shoes, cheap bags, upholstering, novelties, and other articles not requiring stronger and better leather, where the better grades would be too expensive. The skins of calves and other smaller animals are never split, except to remove unevenness, and are tanned whole.

Other Special Leathers.—There are many other varieties and kinds of special leathers on the market. Among the more common are morocco, Russia, and patent leathers. Morocco is generally produced from sheep and goat skins by tanning with sumac leaves or oak bark and afterward coloring with a special dye. Its use is largely for fancy articles. Russia leather is produced with willow or oak bark and afterward stocked with birch-bark oil which gives it an agreeable odor. It is very soft and pliable and is especially valuable for pocketbooks, women's fine gloves, and fancy articles. Patent leather is produced by treating split leather and sometimes grain leather with several coats of linseed oil, rubbing down each coat with pumice stone, and finally polishing the finishing coat with rottenstone. The finishing coat is generally made up of specially prepared linseed oil, thinned with turpentine and naphtha. More recently flexible lacquers similar to those used for automobiles have come into use for patent-leather finishings. It is used for shoes, belts, cases, and the like.

Artificial Leather.—In addition to genuine leather there are several artificial leathers in use. As a rule, these are obtained by treating certain fibers with gelatin or gums and subjecting the mixture to heavy

pressure. Waste leather scraps are also sometimes shredded and treated with gum and pressed into sheets. Artificial leathers are weaker and less durable than regular leather and can be used only in places where strength and durability are not of so much importance.

LEATHER*

For Shoe Bottoms

Outsole	Vegetable-tanned cattle hide Chrome-tanned cattle hide Combination-tanned cattle hide
Insole	Vegetable-tanned cattle hide sole Vegetable-tanned cattle hide split Combination-tanned cattle hide split
Welt	Vegetable-tanned cattle hide Vegetable-tanned pig strips
Counters Toe boxes Heel parts Shank	Vegetable-tanned cattle-hide sole Vegetable-tanned pig strips

For Shoe Uppers

Calf
Kid
Cattle-hide side upper
Buck
Cordovan
Horsehide (glazed)
Kangaroo
Shark
Alligator
Pig (men's only)
Seal, Snake, Lizard (women's only)
Sheep and lamb (children's only)

* Courtesy of American Leather Producers, Inc.

For Shoe Linings

Usually same leather as upper
Otherwise either
  Cattle-hide split lining stock
  Sheep lining stock
  Kid lining stock

Tanbark and Leather and Tanning Terms

bating—Treating dehaired and washed pelts to a bating liquor to remove traces of lime and to make them soft.

beam—A convex wooden bench placed on a slant upon which pelts are fleshed or fine haired.

beamster (beam hand)—The man who works on the pelts on a beam.

cattle-hide leather—Leather obtained from full-grown animals, such as steers and cows.

curing hides—Salting the hides or pelts, as they come from the animals, to preserve them.

dehairing (fine hairing)—Removing the hair from the pelts.

fitter—The man of the peeling crew who rings and splits the bark on the trunk of the tree ready for the spudder to peel.

fleshing—Shaving off the pieces of flesh left on the inside of the pelt when the animal was skinned.

grain—The side of leather from the hair or outside of the pelt.

hides—The pelts of large animals, as steers, horses, and buffaloes.

kips—Pelts from smaller or partly grown animals.

lay-away vats—Vats in which the pelts are soaked in strong liquor, where they receive their final tanning.

leaches—Large circular tanks or tubs in which the tannin is leached or soaked from the tan bark.

liming—Soaking the pelts in lime water to loosen the hair.

liquor—A tanning solution obtained by leaching tanbark in water.

pack—Enough pelts to fill one lay-away vat.

peeling crew—A crew of men (usually four) who fell the trees and peel the bark to get it ready for tanning.

peeling time—The time in the spring of the year when bark will peel easily.

retanned leather—Leather that has been tanned by a combination of chrome and vegetable liquors, the chrome tanning being first and the vegetable second.

rockers—Vats supplied with rocking frames upon which the pelts are hung when first introduced into the liquor.

side—Half of a whole hide split along the line of the backbone.

skins—The pelts of small animals.

sleigh haul—Any ordinary distance that tanbark might be hauled on sleighs.

spent tanbark—Tanbark that has had the tannin leached out or extracted.

split leather—Leather obtained by slicing thick hides into thinner pieces or sheets.

spud—A chisel-like tool used to peel or strip the bark from the tree trunk.

spudder—The man who uses the spud in peeling bark.

stake—A wooden stake supporting a blunt steel blade over which leather is drawn back and forth to stretch, soften, and make it pliable. Staking is done now by a staking machine.

suede—Leather with an unfinished or buffed surface.

tanbark—Any bark that contains tannin in sufficient quantity to be used for tanning leather.

tannery—The plant in which pelts of animals are tanned into leather.

tannin—The element in bark or other vegetable matter that is suited for tanning leather.

vats—Large square tanks generally below the floor in which the pelts are tanned.

Tanbark and Leather and Tanning Questions

Group I

1. What element in tanbark makes it especially useful for tanning leather?

2. What kinds of trees are used most for tanbark production?

3. What is meant by a bark-peeling crew? How many men does it generally comprise?

4. Why is bark peeling done in the spring of the year in the North?

5. How is tannin extracted from bark?

6. What is meant by leaching vats, or leaches?

7. Name some uses for spent tanbark.

8. What is the general name for the hides, kips, and skins of animals?

9. For what general kinds of leather is each of the following used: hides; kips; skins?

10. Why are the pelts limed?

11. Name the general steps through which a hide passes in the process of preparation for tanning.

12. What is meant by split leather?

13. In general, in what sections of the country were small tanneries established in early times?

14. What was the leather produced used for mostly and where did it find its principal market?

15. What other industries are generally found in connection with tanneries?

16. Name some of the other materials used for tanning aside from vegetable tannin extract.

17. How are colored leathers produced?

18. What is meant by oil tanning? What special qualities does oil-tanned leather possess?

19. What is imitation leather? Of what is it made?

20. Name uses for the hair obtained from pelts; from fleshings.

Group II

21. Why should the bark be ground into small pieces before leaching?

22. How is tanbark measured (by the ton or cord)?

23. Explain what is meant by sole leather.

24. Why were many small tanneries formerly established in this country?

25. What conditions made tanneries possible?

26. How may we distinguish between the grain and the flesh sides of leather?

27. Mention advantages of having tanneries connected with shoe factories.

28. Where are tannin-extracting plants likely to be located?

29. Why is tannin extract concentrated before shipping?

30. Name qualities of leather that make it suitable for gloves, shoes, and other articles.

FORESTRY

Strictly speaking, the subject of forestry should not be classified under the head of forest products, but it is so important and closely related to the question that any discussion of these subjects could hardly be complete if it were omitted.

Forestry has to do with the development and perpetuation of the forests, because of their importance in providing wood and other forest products; in preventing erosion of soil and regulating stream flow and water supply for irrigation, power and domestic use; for a haven for wild life and for providing abundant, outdoor, healthful recreational grounds for the people.[1]

Original Forests:

The original forests of the United States, exclusive of Alaska and the island possessions, are estimated to have covered 822 million acres. There are now about 470 million acres of forest land in the United States. Of this area some 138 million acres bear virgin timber; 114 million acres have culled and second-growth timber large enough for sawing; 136 million acres are partially stocked with smaller growth; and 81 million acres are devastated and practically waste land. The total stand of marketable timber is

[1] U. S. Forestry Service.

about 2,200 billion board feet, or at the most about two-fifths of the amount originally in this country. In public ownership in the National Forests are about one-sixth of

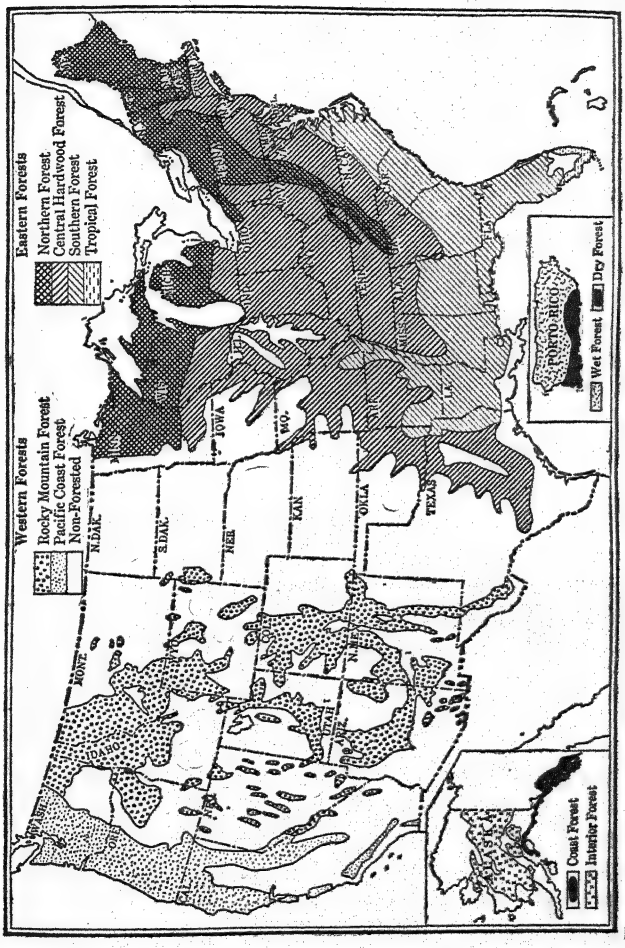

FIG. 75.—Forest regions of the United States, Alaska, and Porto Rico. (*Courtesy of U. S. Forestry Service.*)

the timber lands of the country. These contain about one-fifth of the standing timber, a considerable part of which is now inaccessible because it is located on high mountain

slopes. Another one-half of the forest land is owned by the lumber companies and other large private owners, and one-third consists of woodland on farms[1] (Fig. 75).

Principal Trees of the Forest Regions

PACIFIC COAST FOREST

Northern Portion (Western Washington and Western Oregon):

- Douglas fir[s]
- Western hemlock[s]
- Noble, silver, lowland white, and white firs[s]
- Western red cedar[s]
- Sitka and Engelmann spruces[s]
- Western white pine[s]
- Port Orford cedar and Alaska cedar[s]
- Western and Lyall larches[s]
- Lodgepole pine[s]
- Mountain hemlock[s]
- Oak, ash, maple, birch, alder, cottonwood, madroña[s]

Southern Portion (California):

- Western yellow and Jeffrey pines[s]
- Sugar pine[s]
- Redwood and bigtree[s]
- White, red, lowland, white, and Shasta red firs[s]
- Incense cedar[s]
- Douglas fir[s]
- Lodgepole pine[s]
- Knobcone and digger pines[s]
- Big-cone spruce[s]
- Monterey and Gowen cypresses[s]
- Western and California junipers[s]
- Single-leaf piñon[s]
- Oak, buckeye, laurel, alder, madroña[h]

ALASKA FOREST

Coast Forest:

- Western hemlock (important)[s]
- Sitka spruce (important)[s]
- Western red cedar[s]
- Alaska cedar[s]
- Lodgepole pine[s]
- Mountain hemlock[s]
- Alpine fir[s]
- Black and white spruces[s]
- Balm of Gilead ("balsam poplar")[h]
- Black cottonwood[h]
- Oregon alder[h]
- Alaska white and paper birches[h]
- Willow[h]

Interior Forest:

- White and black spruces[s]
- Alaska white and paper birches[h]

[1] U. S. Forestry Service. [h] Hardwoods. [s] Softwoods.

ALASKA FOREST (*Continued*)

Balm of Gilead[h]
Black cottonwood[h]
Aspen[h]
Tamarack[s]

ROCKY MOUNTAIN FOREST

Northern Portion (Northern Idaho and Western Montana):

Western white pine[s]
Western yellow pine[s]
Western larch[s]
Douglas fir[s]
Lodgepole pine[s]
Engelmann spruce[s]
Western red cedar[s]
Lowland white and alpine firs[s]
Western and mountain hemlocks[s]
White-barked pine[s]
Balm of Gilead[h]

Eastern Oregon and Eastern Washington:

Western yellow pine[s]
Douglas fir[s]
Lodgepole pine[s]
Western larch[s]
Engelmann spruce[s]
Western red cedar[s]
Western hemlock[s]
White, lowland white, and alpine firs[s]
Western white pine[s]
Oak and juniper (in Oregon)[h]

Central Montana, Wyoming, and South Dakota:

Lodgepole pine[s]
Engelmann spruce[s]
Douglas fir[s]
Alpine fir[s]
Limber pine[s]
Western yellow pine[s]
Aspen and cottonwood[h]
Rocky Mountain red cedar[s]
White spruce[s]

Central Portion (Colorado, Utah, and Nevada):

Lodgepole pine[s]
Engelmann and blue spruces[s]
Alpine and white firs[s]
Douglas fir[s]
Aspen and cottonwood[h]
Western yellow pine[s]
Piñon and single-leaf piñon[s]
Rocky Mountain red cedar and Utah juniper[s]
Bristle-cone and limber pines[s]
Mountain mahogany[h]

Southern Portion (New Mexico and Arizona):

Western yellow pine[s]
White, alpine, and cork-bark firs[s]
Engelmann and blue spruces[s]
Douglas fir[s]
Piñon and Mexican piñon[s]
One-seeded and alligator junipers and Rocky Mountain red cedar[s]
Aspen and cottonwood[h]

ROCKY MOUNTAIN FOREST
(*Continued*)

Limber, Mexican white, and Arizona pines[s]
Oak, walnut, sycamore, alder, box elder[h]
Arizona and red-bark cypresses[s]

TROPICAL FOREST

Mangrove[h]
Mahogany[h]
Tree palms[h]

PUERTO RICO FOREST—TROPICAL

Wet Forest:
Mangle (mangrove)[h]
Tabanuco (candlewood)[h]
Ausubo (mastic)[h]
Capa blanca[h]
Guaraguao[h]
Laurel sabino (laurel)[h]
Cedro (Spanish cedar)[h]
Granadillo[h]
Guasima[h]
Majagua[h]
Moca[h]
Palms[h]
Santa Maria[h]
Roble[h]

Dry Forest:
Guayacan (lignum vitæ)[h]
Guava[h]
Guama[h]
Mora[h]
Algarrobo[h]
Jobo[h]
Ceiba (silk-cotton, or kapok,[h] tree)
Almacigo[h]

SOUTHERN FOREST

Pine Lands:
Long-leaf, short-leaf, loblolly, and slash pines[s]
Southern-red, turkey, black, post, laurel, and willow oaks[h]
Black gum[h]
Pond, spruce, and sand pines[s]

Alluvial Bottoms and Swamps:
Southern cypress[s]
Red, tupelo, and black gums[h]
Water, laurel, live, overcup, Texas red, and swamp white oaks[h]
Yellow poplar[h]
Hickories (including pecan)[h]
Beech[h]
Ash[h]
Red and silver maples[h]
Cottonwood and willow[h]
Elm[h]
Sycamore[h]
Hackberry[h]
Honey locust[h]
Bay[h]
Magnolia[h]
Spruce pine[s]
Southern white cedar[s]

CENTRAL HARDWOOD FOREST

Northern Portion:

White, black, northern red, scarlet, burr, chestnut, and chinquapin oaks[h]
Shagbark, white-heart, pignut, and bitternut hickories[h]
White, black, green, and red ashes[h]
American, rock, and slippery elms[h]
Red and sugar maples[h]
Beech[h]
Pitch, white, short-leaf, and Virginia pines[s]
Yellow poplar[h]
Sycamore[h]
Chestnut[h]
Black walnut and butternut[h]
Cottonwood[h]
Hackberry[h]
Black cherry[h]
Basswood[h]
Red cedar[s]

Southern Portion:

White, post, southern red, blackjack, chestnut, swamp chestnut, pin, and overcup oaks[h]
Red and black gums[h]
White-heart, pignut, pecan, and nutmeg hickories[h]
Short-leaf and Virginia pines[s]
White, blue, and red ashes[h]
Yellow poplar[h]
Black locust[h]
Elm[h]
Sycamore[h]
Black walnut[h]
Silver and red maples[h]
Beech[h]
Buckeye[h]
Dogwood[h]
Persimmon[h]
Cottonwood and willow[h]
Red cedar[s]
Osage orange[h]

Texas Portion:

Post, southern red, and blackjack oaks[h]
Mountain and other cedars[s]

NORTHERN FOREST

Northern Portion:

Red, black, and white spruces[s]
Balsam fir[s]
White, Norway, jack, and pitch pines[s]
Hemlock[s]
Sugar and red maples[h]
Beech[h]
Northern red, white, black, scarlet, and burr oaks[h]
Yellow, paper, black, and gray birches[h]
Aspen (poplar) and cottonwood[h]
Basswood[h]

NORTHERN FOREST (*Continued*)

Elm[h]
Ash[h]
Northern white cedar[s]
Tamarack[s]

Southern Portion (Appalachian Region):

White, northern red, chestnut, black, and scarlet oaks[h]
Chestnut[h]
Hemlock[s]
White, short-leaf, pitch, and Virginia pines[s]
Yellow poplar[h]
Black and yellow birches[h]
Basswood[h]
Sugar, silver, and red maples[h]
Beech[h]
Red spruce[s]
Southern balsam[s]
Cucumber[h]
Black cherry[h]
Hickory[h]
Black locust[h]
Black gum[h]
Buckeye[h]

NOTE.—The order indicates the relative importance or abundance of the trees.

For many years after settlement began, especially in the Eastern parts, the question was not one of conservation and economic use of the forests but rather how could they be removed to make room for the settlers. The pioneer was naturally more concerned with pushing the forests back to make room to raise crops for food than he was in growing trees for future generations. Confronted, as he was, on all sides by vast forests that many times were a hindrance rather than an aid, he naturally did not develop a strong sense of respect for the trees. So vast indeed were the forests that nobody seemed to dream that they were not inexhaustible, and therefore there seemed little use of bothering about conservation.

Early Attempts at Forestry.—It is true that attempts were made from time to time in different sections to provide for better forest management, but these

were local in their nature and always inaugurated because of some special local need. The following

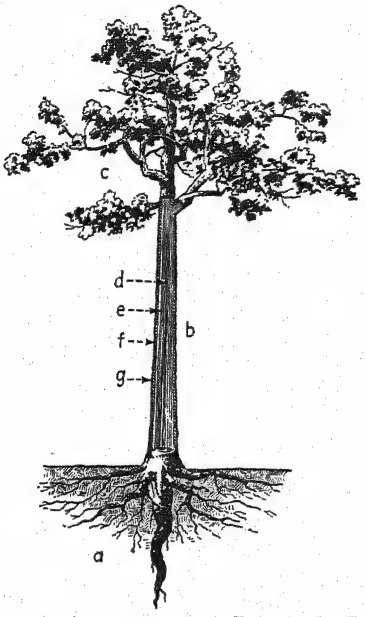

FIG. 75*a*.—How a tree grows. *a*. Roots. *b*. Trunk. *c*. Crown. *d*. Heartwood. *e*. Sapwood. *f*. Inner bark. *g*. Outer bark. Trees increase each year in height and spread of branches by adding on a new growth of twigs. The buds, root tips and cambium layer are the growing parts of the tree. The leaves manufacture food for the growing processes from materials obtained from the air and soil and give off moisture by transpiration. Water containing minerals in solution is absorbed by the roots and carried up through the sapwood to the leaves. There the water and minerals combine with carbon which is taken from the air by the under surface of the leaves. This food is carried by the inner bark to all growing parts of the tree, even down to the root tips. The tree takes in oxygen over its entire surface through breathing pores on leaves, twigs, branches, trunk, and roots. (*Courtesy of U. S. Forestry Service.*)

will give an idea of the nature of some of these movements. A court decree in New Plymouth:

Orders agreed on at several times for the good of the Colony: It was decreed by the court held on the 29 of

March. Anno. 1626. That for the preventing of which inconveniences, as due, and may befall the plantation by want of timber, that no man of what condition soever sell or transport any maner of works or frames, for homes, planks, bords, shipping, shalops, boats, canoes, or what so ever may tend to the destruction of timber aforesaid: how little so ever the quantity be, without the consent, approbation & liking of the Governour & Counsell.

One of William Penn's requirements was that one acre of forest land should be left for every five acres cleared. As early as 1799 Congress appropriated money to purchase forest reserves containing timber to ensure a quantity of ship-building material, as a measure of national defense.

Several of the states also began early to take stock of their timber assets, but no nation-wide movement for forest conservation was inaugurated until 1876, when a federal forestry agent was appointed to study forest conditions. It was not until about ten years later, however, that any definite general action was taken, when a division of forestry was created in the Department of Agriculture. At first, the activities of this division were limited to studying and spreading information concerning forest conditions, but its work has gradually expanded until it takes in a long list of forest activities and is one of the most important conservation agencies in the United States government.

United States Forestry Service.—The division now known as the U. S. Forestry Service is under the direction of a chief forester and his associate at

Washington, who has general charge of forestry matters of the United States and our territories. The service is organized under two heads: the Washington office and the field service. The whole country, including Alaska and Puerto Rico, is divided into ten regional sections, with a regional forester in charge of

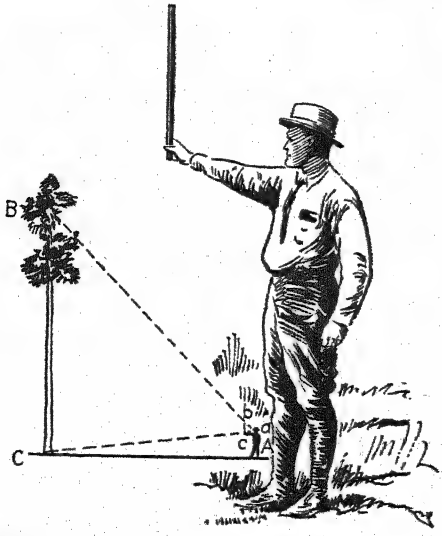

FIG. 76.—Measuring height of tree by use of tree-scale stick. *ac* is to *AC* as *cb* is to *CB*. (*Courtesy of U. S. Forestry Service.*)

each and several administrative branches under heads of operation (Fig. 77). In connection with the research branch, forest-products laboratories are maintained at Madison, Wis., and, in addition, twelve experiment stations are distributed in different parts of the country. The principal duties of the Forestry Service are to manage and supervise the use of the national forests, to cooperate with the states in their

betterment, and to disseminate knowledge concerning forest conditions and forest management. As one of the most important branches of the work of the Forestry Service is in connection with the national forests, a brief discussion of these will be given.

National Forests.—National forests are large tracts of land owned, set aside, and controlled by the national government mainly to ensure a perpetual supply of timber for home industrial use, to prevent the destruction of forest cover which controls the flow of streams, to afford protection for wild life in its natural surroundings, and to reserve natural recreation grounds for the people. The national forests include about one-third of the nation's standing timber.

There are about 160 of these forests in the United States comprising over 175,000,000 acres of land, mostly in the mountain ranges of the West (Fig. 77), although we also find them scattered elsewhere, as far east as the state of Maine and as far south as Florida. In describing the national forests the Forestry Service made the following statement:

From the hardwood of the Southern Appalachians to the spruces of the White Mountains of New England, from the piñon and juniper stands where tree growth begins in the southern Rockies of New Mexico to the pine and fir forests of the Canadian line in Montana and Idaho, from the brush-covered hills of the San Jacinto and San Bernardino Mountains in Southern California to the vast softwood stands of the Olympics and Cascades in northern Washington, the national forests lie mainly on the mountain slopes. Even along the Alaskan shore, where the Tongass and

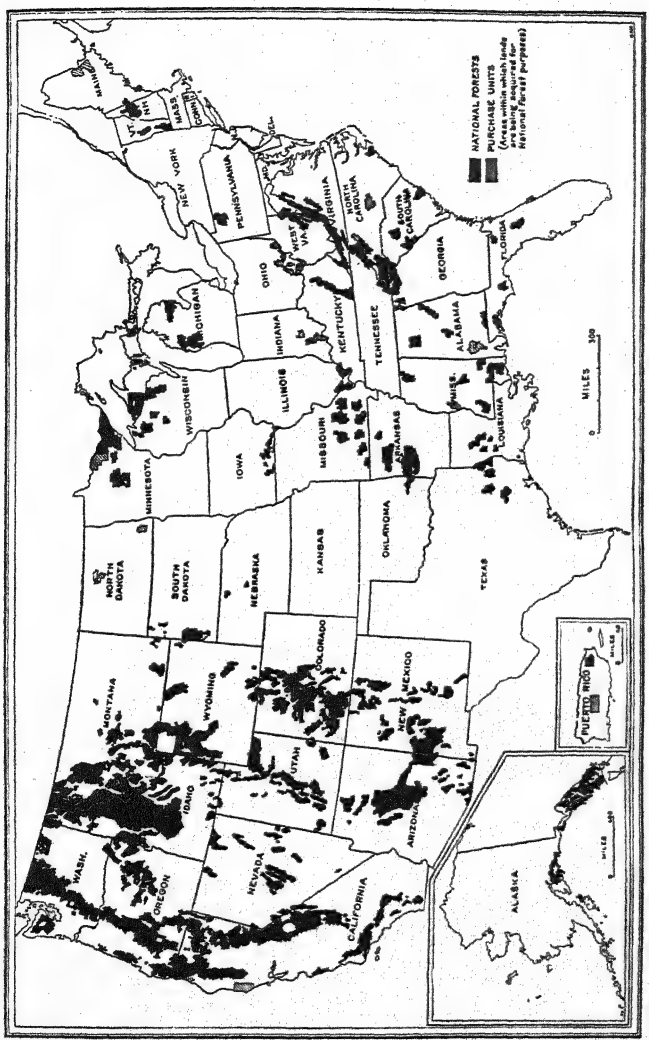

FIG. 77.—National forest areas in the United States. (*Courtesy of U. S. Department of Agriculture.*)

Chugach forests form a tattered ribbon 600 miles long from the tip of the territory to within sight of Mount McKinley, the valuable Sitka spruce and hemlock growth clothes the lower flanks of the coastal mountains.

For the most part, in the Western section, the lands now occupied by national forests originally belonged to the federal government. Consequently all that was necessary to retain control was to withdraw the land from entry. In the Eastern sections the national forest lands have been purchased from the states or from private individuals or received as gifts.

The following paragraphs will give an idea of the work of the Forestry Service in these national forests:[1]

With a view to slashing red tape and avoiding bureaucratic delays the national forests have been divided into eight administrative districts. Each of these districts is under the direction of a district forester, whose work is directed by several branches charged with special duties. He is assisted by assistant district foresters, immediately charged with the specialized work carried on in the district. Each forest is run by a forest supervisor, who has a deputy when the work of administration requires.

Each national forest is further divided into ranger districts. The forest ranger is the watch dog of the forest. He supervises timber sales, grazing and other uses of the forests. He helps build trails, roads and bridges and string telephone lines. In addition there are field men needed in connection with logging and reforestation work. During the period of greatest fire danger forest guards are employed temporarily.

[1] Courtesy of American Tree Association.

Various lines of technical and administrative work must be carried on in running a forest. This is done by assistants chosen through technical examinations. After a period of practice these assistants are eligible for posts of forest examiners, doing work of mapping areas, examining

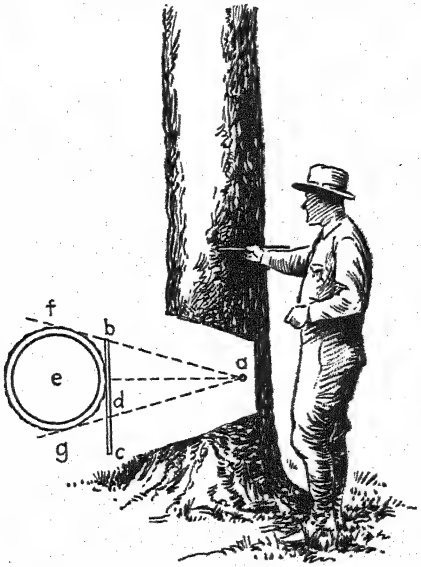

FIG. 77*a*.—Measuring tree diameters by using a tree-scale stick: *ab* is to *bd* as *af* is to *fg*. (*Courtesy of U. S. Forestry Service.*)

timber, carrying on planting or nursery work, and marking timber for cutting.

Utilization of National Forests.—As has been stated, the purpose of the national forest movement is largely one of conservation of our natural resources. Lumbering and other industrial activities are permitted on them but must be carried on under supervision and proper restrictions. Parties wishing to engage in lumbering on these lands may purchase the timber,

or "stumpage" as it is called, but not the land upon which it stands. Logging and other operations must be carried on conservatively according to regulations prescribed by the Forestry Service. Only certain kinds of trees and those above a given diameter may be cut; care must be exercised in felling and other activities to avoid damage to the young trees. Tops and branches must be lopped, burned, or otherwise cared for to avoid menace in case of forest fires; precautions must be taken to eliminate the danger of fire from steam sawmills, locomotives, and other sources; in fact the operator contracts to use every reasonable precaution to leave the forest in good condition for its natural growth and development after his timber has been removed. Homestead settlers and farmers may obtain national forest timber for their own use at the actual cost of making the sale. No charge is made to them for the timber itself.

A considerable percentage of national forest areas is not stocked with trees and in many instances is well adapted to grazing. Provision has been made by the government to issue permits to stock men for this purpose. Mining rights can also be secured, and special inducement is made for the utilization of water-power sites and the construction of telephone and telegraph lines by private parties. In recent years also special attention has been given to making the national forests available and desirable as public recreation grounds. Good roads have been constructed to more remote and picturesque parts, camping grounds have been provided, guide assistance

made available, and other measures taken for the comfort and happiness of the visitors. Briefly stated, the whole national forest movement is for the purpose of controlling and managing these public domains not only to render them of the greatest benefit to the greatest number of people now living but also to pass them on unimpaired to posterity.

State Forestry.—What the U. S. Forestry Service is to the nation the state forestry departments in a way are to their respective states, except that their duties are more in the line of supervision and management of state parks and cooperation with individuals in reforestation and better management of privately owned forest lands.

Historical Forest Fires.—It is estimated that for every cubic foot of wood cut from the forests for a useful purpose at least three are destroyed by forest fires.

Before discussing the present conditions it might be well to mention a few of the more destructive historical forest fires that have occurred in this country. In 1825 a forest fire occurred at Mirimichi, Wis., which, in nine hours, swept over a tract approximately 25 miles wide and 80 miles long. In this fire 500 persons perished, nearly 600 buildings were burned, and millions of dollars worth of timber and other property destroyed. At Peshtigo, Wis., a forest fire occurred in 1871 in which between 1,200 and 1,500 people lost their lives, several hundred buildings were burned, and an enormous amount of other property was destroyed. At Hinckley, Minn., in 1894 several

whole towns were wiped out, over 500 persons were killed, and 2,000 were made homeless. The years 1899, 1903, and 1908 were noted for destructive fires in the Adirondack Mountains, in which thousands of acres of timber land were practically denuded of trees. In some places the humus soil was so completely burned that reforestation for many years to come in that section was practically impossible. The year 1910 was marked by a great forest fire in Idaho in which 1,600 square miles of territory were burned over, and upward of 80 people perished. This fire occurred in a high wind, and it is stated that in places it swept over the ground faster than a horse could run. These are a few of the more outstanding forest fires that have occurred in our history, but they rage to a greater or lesser extent every year, and no season passes by without their toll of human life and destruction.

Types of Forest Fires.—There are three types of forest fires: surface fires, ground fires, and crown fires. Surface fires run over the ground and burn the dry leaves and other litter. As a rule, their greatest damage is in destroying young trees and scorching or burning seeds so that they will not germinate. There is always danger, however, that surface fires may develop into ground or crown fires and do great damage.

Ground fires occur in forests having considerable duff, or humus, soil on the forest floor, which will sustain combustion. The extent of the damage done by these fires is determined by the length of the

drought and the depth of the combustible material in which they are burning. They often injure the roots of trees, causing them to die outright, or severely stunt them in their growth. Often these fires will smolder for days or even weeks before they are extinguished.

Crown fires are those that burn in the tops and branches of the trees. They occur in high winds, more especially in cone-bearing trees where they are fed by inflammable gums and dead branches. They are the most destructive type of forest fires.

Causes of Forest Fires.—Most of the causes of forest fires are the results of carelessness and are well known, although it is not easy to fix the responsibility. Railroad locomotives throw off into dry grass or other débris sparks that are fanned into flames long after the trains have passed. This often occurs in the night when there is no one around to put the fire out. This source of danger, however, is overcome to a certain extent by the use of spark arresters on the locomotive smokestacks, but they sometimes interfere with the draught and are not always properly adjusted. In some sections oil burners are required on the railroads, and they practically eliminate the fire hazard from this source.

Sometimes campers are careless and either make no attempt to extinguish their fires before leaving or are not thorough in preventing embers, smoldering in the ashes, from being fanned into flames by the first passing breeze. (The Boy Scout movement and other agencies are doing good work in their efforts to educate the public to the importance of precaution

in this respect. President Roosevelt said of the Boy Scouts: "The trees and forests have no better friends than the Boy Scouts of America, which teaches reverence for nature's handiwork and inspires active service in its production and conservation." This movement is of increasing importance because of the large number of campers that visit our forests all over the country every year.)

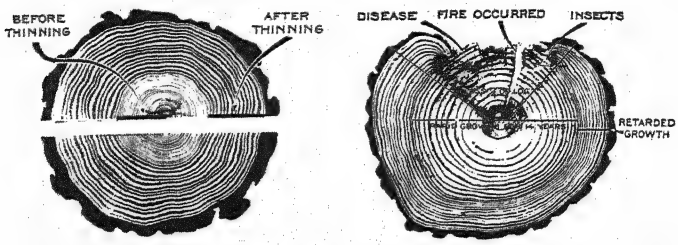

FIG. 77*b*.—How thinning increases growth is shown on the left. On the right is shown how fire ruins timber. Disease and insects enter through fire scars. (*Courtesy of U. S. Forestry Service.*)

Careless smokers often set the forests on fire unwittingly by throwing lighted matches, smoldering cigarettes, cigar stubs, or tobacco into the dry leaves; hunters set the leaves on fire with bits of burning charge from their guns; fallow burning sometimes gets beyond control and spreads to the surrounding forests; berry pickers like to burn the ground over to increase the crop of berries the following season; lightning causes many fires; people have been known to set the forests on fire for spite; and it is even reported that at one time the mountains of the Adirondacks were burned over as a celebration for the Fourth of July.

Forest-fire Fighting.—The best time to fight a forest fire is at its beginning. For this reason the

government and other agencies owning large tracts of forest lands have established lookout stations in commanding places where distant fires can be detected in their incipience (Fig. 78). These stations are connected by telephone lines to central stations where often fire-fighting crews are ready to leave on a moment's notice. In some instances boxes of fire-fighting tools are placed at strategic points where they are available for the fire fighters without the loss of time. In recent years airplanes have been used to good advantage in detecting remote fires before they got beyond control and by sometimes actually dropping fire fighters and supplies. Of course a copious supply of water is the most efficient means of putting out a fire, but this is not often available in the case of forest fires. Fresh earth or sand thrown on a ground fire will often extinguish it unless it has gotten under too great headway. Often small ground fires can be extinguished by whipping with brush or old gunny sacks. As a rule ordinary ground fires can be stopped by a fire line which can be a roadway clear of inflammable material, a furrow of fresh earth, or a ditch. Backfiring is also efficient for stopping ground fires.

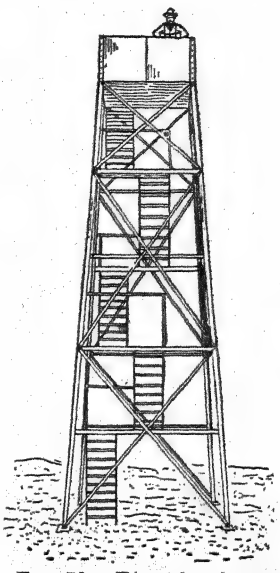

FIG. 78.—Fire-lookout tower. (*Courtesy of U. S. Forestry Service.*)

This consists of burning, under control, a strip clear of inflammable materials in the path of the main fire, thus leaving nothing for the main fire to feed upon. Backfiring must be guarded very carefully to prevent its getting beyond control.

Reforestation.—One of the most important problems in connection with the forest situation is that of reforestation. There are two general types of land where this is especially important: (1) cut-over lands not intended to be cleared for agricultural purposes, where logging operations have not been followed by satisfactory natural reproduction, and (2) abandoned farms and other lands that are lying idle and practically unproductive.

Unless the soil has been badly eroded by floods or destroyed by forest fires, in most instances nature sets about to replace the trees unassisted as soon as a timber crop is removed. In the case of some of the hardwoods, sprouts spring up around the stumps and from the roots of the parent trees. This method is often sufficient to warrant a normal growth of such trees for the future. But in the case of the softwoods, as pines, hemlock, and spruces, reproduction is from the seeds. (It is a curious fact that a mixed hardwood forest is apt to spring up naturally on land formerly occupied with cone-bearing softwoods.)

In planting, attention must be given to the kind and nature of the soil, the climatic conditions, and the particular species of trees that will thrive in a particular locality. In the Northeastern states the conifers are more widely used for planting than the

hardwoods, and of this group white pine seems best adapted for the various kinds of soils, although the planting of spruce for paper pulp is receiving considerable attention.

Seedlings for planting can be secured from private dealers or, in many cases, from the state nurseries. A number of the states own and operate tree nurseries, not only to furnish seedlings for foresting state lands but also to distribute to their citizens for private planting. As a rule, these seedlings are sold at cost

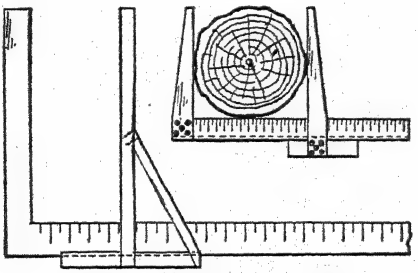

FIG. 79.—Homemade tree caliper.

and can often be purchased as low as a dollar or two per thousand. As another inducement for private forest tree planting some of the states have made special tax reduction on private land used for the purpose.

Forestry Education.—Scientifically managed forests require scientifically trained men. In this connection the facilities for education in the principles of forestry have generally kept pace with the public sentiment. Some of the universities and colleges have established courses leading to such degrees as Bachelor of Science of Forestry, Bachelor of Science of Forestry Engineer-

ing, Master of Forestry, and others. In addition, many schools are giving short courses in special branches of forestry work, and practical men are being trained on the field and become regular forest assistants.

One of the encouraging developments in the past few years has been the awakening of educators all over the country to the importance of teaching the principles of forest conservation in the schools. Arbor Day is now observed in most of the states, and the pupils are supposed to plant trees or carry out some other appropriate program. The inauguration of American Forestry Week served to organize the schools in the interest of forestry. At one time it was observed in nearly all the states, but unfortunately it has not been kept up. Many institutions as well as cities and towns own and control forest tracts upon which public demonstrations in forestry practice are given. Considerable important educational work is also being done in boys' and girls' summer camps by field forest officials, especially in the national forests. In addition to these agencies the U. S. Forestry Service, the state forestry departments, and other institutions are distributing literature on the subject free of charge to anyone who may be interested.

Although a great deal has been done to advance the interests of forest conservation, a great deal more still remains to be done. If all the forests belonged to the national government and the states, the problem of forest management would be comparatively simple. But this is not the case. By far the largest percentage

of these lands is owned and controlled by private individuals, and no one can dictate to the owner how or when he shall cut his trees or whether or not he shall plant forest trees on his own land. The whole matter is largely one of public education and the creation of the proper public sentiment.

FIG. 79*a*.—Forest ranger running a line with a transit. (*Courtesy of U. S. Forestry Service.*)

Forestry Terms

acreage—A definite tract or number of acres of forest land.

backfire—A fire started purposely and burned under control in the path of a forest fire to stop the forest fire.

conservation—The care, protection, and judicious use of the forests.

coppice—The growth of young trees in the forest, especially after the larger trees have been cut away.

dibble—A tool for making holes for planting seeds or young trees.

duff—Leafy mould on the forest floor.

fire line—Any strip of land free from combustible materials, as a road, ditch, furrow, or burned-over stretch that will stop a ground fire.

fire warden—An official having immediate charge of a section of forest to watch for and guard against forest fires.

forest cover—The leafy mould, or covering, on the ground under the trees. (See Duff.)

forest crop—The amount of lumber and other merchantable wood that can be taken from a forest tract at any one cutting.

forest ranger—An official having immediate charge of the management and care of a forest section. The official on the premises.

forest reserve—A tract of forest land set aside for some special purpose, as a park, a national forest, a watershed, or an animal range.

forester—One who practices forestry as a profession.

forestry—The science of forest management.

humus—See Duff.

lumbering—Cutting logs and manufacturing them into lumber.

mature trees—Trees that have reached their normal size, or growth, and should be cut.

mixed forests—A forest containing several kinds of trees.

national forests—A forest owned and controlled by the national government.

national park—A tract of land, forest or otherwise, owned by the federal government and held exclusively for recreational purposes (example, Yellowstone National Park).

pure forest—A forest composed of one kind of tree.

reforestation—Generally, planting trees where they have been removed.

seedling—A small tree grown from the seed.

stumpage—The estimated amount of lumber or timber that can be produced from a given tract.

United States Forestry Service—A division of the U. S. Department of Agriculture charged with the administration and

care of the national forests and assisting in all forest conservation in the United States and territories.

windfall—An area in which the trees have been blown down by the wind.

working plan—A definite plan for the best use and management of forests.

Forestry Questions

Group I

1. What is meant by forest conservation?

2. Explain what is meant by the U. S. Forestry Service, and mention some of its duties.

3. Mention some of the common causes of forest fires.

4. Give some of the most efficient means of fighting forest fires.

5. What effect do forests have on the rivers and other streams?

6. Name types of land especially suitable for reforestation.

7. Mention uses for national forests besides producing lumber.

8. Mention some of the duties of the forest ranger.

9. What is meant by a fire tower?

Group II

10. What is the essential difference between a national park and a national forest?

11. What is meant by conservative lumbering?

12. To what officials should you apply for information concerning forest matters?

13. Mention measures that can be taken to prevent forest fires.

14. How do the forests prevent floods?

15. How do cattle and sheep destroy the forests?

16. Do you think that a man who plants a tract of forest trees on his own land should have his taxes reduced? Explain your answer.

17. Why is the life of a forest ranger healthful?

18. Why was little attention given to forestry in the early history of our country?

AVERAGE COMPARATIVE PROPERTIES OF COMMON WOODS OF CONSTRUCTION*

Name or kind of wood	Weight per cubic foot, dry pounds	Comparative strength				
		Bending	Compression	Stiffness	Hardness	Shock resistance
Hardwood:						
Apple	47	85	75	139	119	146
Ash, white	42	113	106	168	107	153
Basswood	26	61	62	126	31	54
Beech	48	76	66	114	116	296
Birch, yellow	43	106	98	174	86	171
Butternut	27	64	68	115	40	80
Cherry, black	35	93	100	150	72	112
Chestnut	30	68	70	112	50	69
Elm, American	36	85	74	130	66	123
Gum, red	34	86	77	134	60	99
Hickory, shellbark	48	126	105	165	...	308
Maple, sugar	44	114	106	178	115	138
Oak, live	62	142	130	228	240	148
white	48	102	96	152	108	127
red	44	99	88	164	103	143
Poplar, yellow (tulip)	28	71	68	135	40	58
Sycamore	35	74	76	129	64	78
Walnut, black	39	111	113	167	88	124
Softwood:						
Cedar, red	33	67	87	80	81	114
white	22	50	52	78	30	47
Cypress	32	79	92	136	52	76
Fir, Douglas	34	90	107	181	59	81
Hemlock	28	72	79	121	51	67
Larch	36	89	104	153	64	81
Pine, long-leaf	41	106	123	189	76	103
pitch	34	80	76	146	56	96
white	27	69	75	137	35	65
Redwood	30	90	104	134	59	70
Spruce, black	28	68	70	143	40	82

* Courtesy of U. S. Forest Service.

19. Why do we find most of the national forests in the Rocky Mountains?

20. How can airplanes be used in fighting forest fires?

21. Why is a study of forestry desirable in city schools?

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CHAPTER II

NON-METALLIC MINERALS

PETROLEUM

Petroleum (rock or mineral oil) is a liquid bitumin of the hydrocarbon family. It is a very complex compound but generally contains about 80 to 88 per cent carbon and from 10 to 15 per cent hydrogen. The other elements are sulphur, oxygen, nitrogen, and metallic salts. Petroleum gets its name from two suggestive Latin words, *petra* meaning "rock" and *oleum* meaning "oil" or "fat." One theory in regard to its source is that it is the result of the distillation of organic matter (both animal and vegetable) by heat and great rock pressure over a period of many centuries. The amount of heat, the character and pressure of the rocks, and the time the process has been going on largely determine the nature of the petroleum. Generally speaking, there are two kinds of petroleum: that with a paraffin base and that with an asphalt base. From the paraffin-base group we obtain the waxes that are used as preservatives, for sealing wax, and in medicinal work, and from the asphalt-base group the asphalts used for pavements, roofing, waterproofing, and petroleum coke. The oil varies in color from nearly water white through shades of green and brown to jet black and in consistency from light and watery to a heavy, viscid, sticky substance.

Historical.—The use of petroleum dates back for many centuries. It was the bonding material in the mortar of the walls of ancient Nineveh and Babylon. Early Greek and Roman writers mention its use. The American Indians knew and used it long before the advent of the white man and afterward sold it to the early settlers for medicine under the name of Seneca Oil. "Bitumin fountains" were reported by missionaries to exist in what is now western New York early in the seventeenth century. It was known to the early settlers of northwestern Pennsylvania, where it oozed from the rocks and floated on the streams. There is a story of one farmer of that section who became disgusted and sold his farm very cheap because he was obliged to go out every morning and push back the scum from the surface of the water in the creek before his cows could drink; in less than a year the same farm sold for a fabulous price as oil land.

Early salt wells in the Ohio River valley were abandoned because the brine came up mixed with black oil that spoiled the salt.

It was not until after the middle of the past century that the production of petroleum in this country took on any great commercial importance. The first successful well was drilled by Edwin Drake at Titusville, Pa., in 1859. His adventure was looked upon by many with skepticism. People derided and called it "Drake's folly." But Drake kept on drilling as long as he had any money; and when all of his own was gone he borrowed from his friends. He never

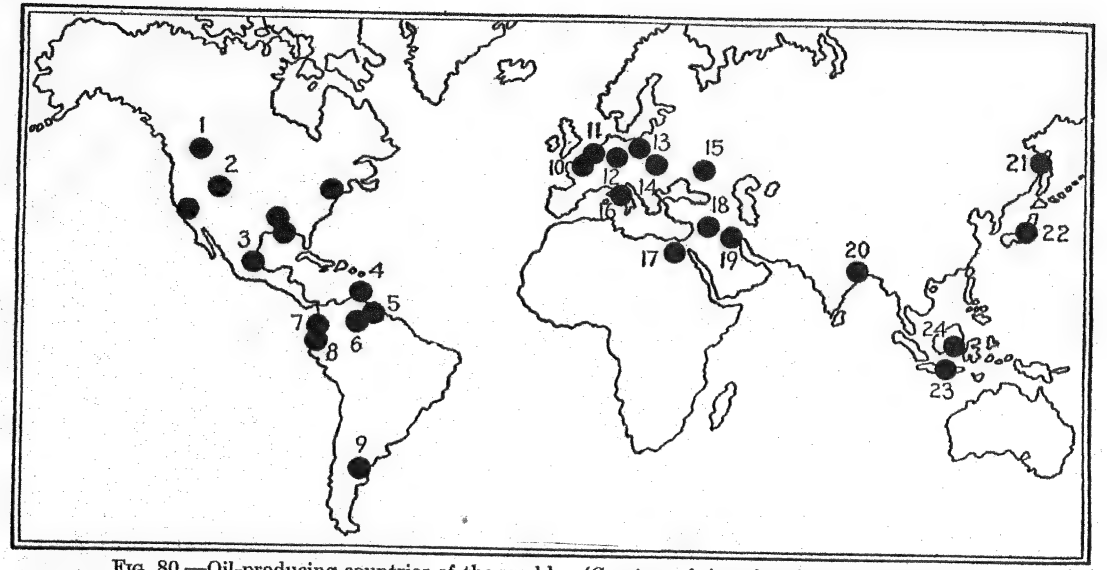

FIG. 80.—Oil-producing countries of the world. (*Courtesy of American Petroleum Institute.*)

1. Canada
2. United States
3. Mexico
4. Trinidad
5. Venezuela
6. Colombia
7. Ecuador
8. Peru
9. Argentina
10. France
11. Germany
12. Czechoslovakia
13. Poland
14. Rumania
15. Russia
16. Italy
17. Egypt
18. Iraq
19. Persia
20. India
21. Sakhalin, Russian
22. Japan and Taiwan
23. Netherlands India
24. Sarawak, British Borneo

lost faith in his project and never slackened his efforts until he had struck oil in paying quantities. Although Drake's well has long since ceased to produce oil, it is pointed to as the real beginning of the development of the American oil industry. A monument bearing a bronze inscription plate has been erected to Drake on the spot where his well was drilled as a reminder to the world that American genius and perseverance know no defeat.

Immediately after Drake struck oil, there was a blaze of excitement. Owners of small barren farms suddenly found themselves millionaires. Fortunes were made and lost overnight. People rushed to the new oil fields from all directions, and the get-rich-quick frenzy equaled or exceeded that of the gold rush for California ten years before. From that time on the discovery of new fields and the production of oil have advanced by leaps and bounds. At the present time it is not only a world-wide industry indispensable to mankind in and of itself, but also the basis of a great many other industries.

Distribution of Petroleum.—Petroleum is found in nearly every country in the world, in at least a small quantity. As with coal and iron, the United States leads all other countries in the extent of its known fields and in production. In 1927 it furnished 70 per cent of the world's supply.

The oil fields in this country can be grouped, in general, as follows: (1) the Appalachian field, comprising the pools of central Ohio, Pennsylvania, New York, West Virginia, Alabama, Kentucky, and Ten-

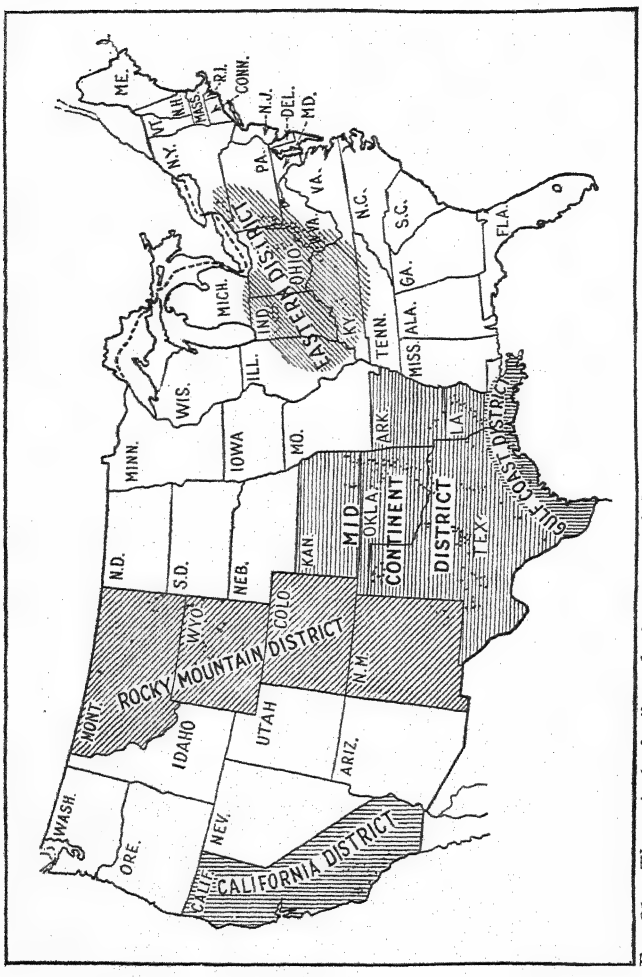

FIG. 81.—The principal oil-producing areas of the United States. (*Courtesy of American Petroleum Institute.*)

nessee; (2) the Lima-Indiana field, including the pools of Indiana; (3) the Illinois field, including the pools of that state; (4) the Mid-Continent field, including Kansas, Oklahoma, Arkansas, Louisiana, Texas, eastern New Mexico, and Oklahoma; (5) the Rocky Mountain field, including Colorado, Wyoming, Montana, Utah, and parts of New Mexico; and (6) the California fields (Fig. 81). The U.S.S.R. stands second in production, with Venezuela third, Mexico

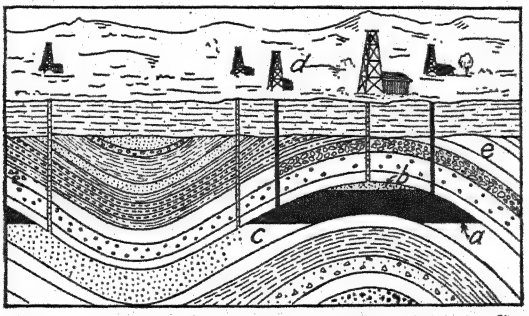

FIG. 82.—Cross-section showing oil pool. *a.* Oil pool. *b.* Gas pocket. *c.* Salt water. *d.* Oil derrick. *e.* Earth.

fourth, and Persia fifth (1928). These positions, however, are only relative, as is shown by the fact that Mexico occupied second place in 1926. Greater or lesser quantities of oil are also being produced in the Dutch East Indies, India, Rumania, Japan, Argentina, Colombia, Trinidad, and other countries.

Methods of Detecting Oil Pools.—In the early years of the industry drilling for oil was more or less of a gamble and is to a certain extent at the present time. Certain surface indications exist that oil may be found in a locality, but these signs are not always

reliable. Professional oil smellers formerly went about claiming that they could locate oil pools by smelling the ground. In some instances so-called "divining rods" were brought into use. One of these devices was the crotch of a witch-hazel branch in the hands of an expert diviner. If the diviner was unable to hold the branch still in a certain position, it was supposed to be a sure indication that oil pools were underneath. All of these methods were at least interesting and always worked well when oil happened to be found.

In recent years, however, science has stepped in and greatly simplified the problem of locating oil fields. The presence of oil pools underlying a locality is largely indicated by the character of the rocks in that locality. Consequently, if the character of these rocks can be determined to any considerable depth, it is fair to assume that oil can or cannot be found there. In this connection the seismograph is used to record the tremors in the rocks set up by a violent explosion just as it records those made by an earthquake. Several portable seismographs are located a few miles distant around a central point where a large charge of dynamite is exploded in the ground. The rates of the vibrations of the rocks are recorded by the seismographs and from them the nature of the rocks is determined. Many of the important oil fields in the United States are associated with salt rocks. It is known that the vibrations in these rocks travel faster than in other kinds; consequently, when the seismograph records exceptionally rapid

travel of the vibrations, it is a fairly good indication that oil can be found underneath.

Another method of detecting the presence of oil in a certain locality is by the use of the so-called "torsion balance," which depends for its action on the principle that the denser the matter the more greatly the force of gravity acts upon it. This device consists of a nicely balanced machine suspended in a horizontal position from a central point. As oil sands are often associated with salt-rock domes, and as there is a difference between the attraction of the sands and the rock, when the balance is passed over the locality, it will be deflected or twisted at a different speed and indicate that oil may be found below. Other methods are by the use of electricity. A rotary drill stem is made up of two concentric pipes fastened together but insulated from each other, and at the end of which the drill bit is attached. An electric current is passed down one of the pipes and up the other and for a short distance at the bottom must go through the rock being drilled. A registering device at the surface indicates the character of the rock through which the current passes. In another electrical method, electrodes are placed in the earth at intervals some distance apart, and a current is sent through them that also—theoretically, at least—passes through the intervening rocks to a depth equal to the distance between the electrodes, thus registering the character of the rocks in that locality.

Tests are also being made with an instrument known as a "magnetometer" that measures the mag-

netic attraction of the rocks underneath. Rocks with a higher percentage of iron naturally have greater magnetic attraction than others. By taking readings in many points in a locality and calculating the results, a fair determination of the character of the rocks below can be made and also their depth from the surface. A more recent development in the search for oil is the so-called "soil-air" analyses. The soil and

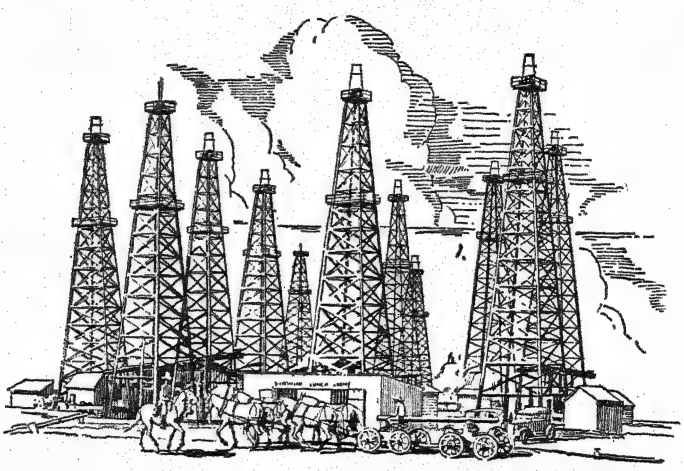

FIG. 82*a*.—View of an oil field. (*Courtesy of American Petroleum Institute.*)

air of a section is analyzed and, if minute quantities of hydrocarbons are found, it is a fair indication that petroleum deposits are underneath.

Drilling.—When it is reasonably sure that a pool has been located, wells are sunk and other preparations made for recovering the oil. If the materials met with in drilling are very hard, some form of chisel drill is used. If they are soft enough, the rotary type of drill can be used, which generally works faster

(Fig. 83). As the drilling proceeds, a casing (pipe) is lowered into the hole to keep out the gravel and other materials. Often special cement is introduced into a well to seal up openings in the pipe to keep out

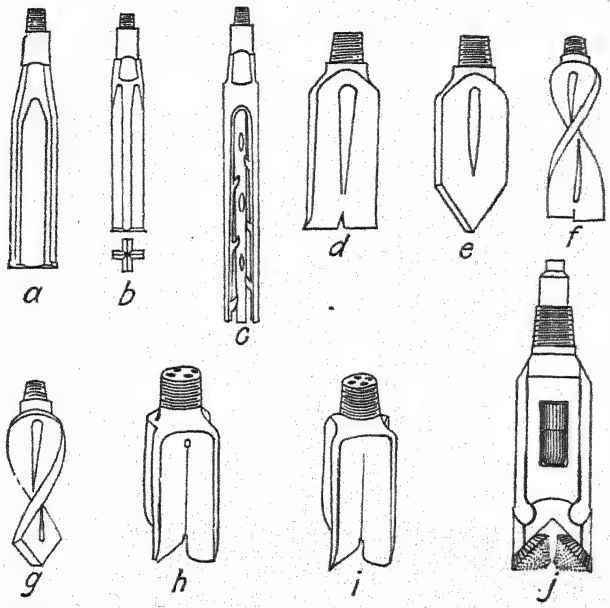

FIG. 83.—A few types of drills used for oil wells. *a*. California pattern, *b*. Star or four-wing pattern. *c*. Fishing tool. *d*. Fishtail. *e*. Diamond point. *f*. Fishtail twist. *g*. Diamond-point twist. *h*, *i*. Four-wing rotary. *j*. Rock bit. (*Courtesy of Oil Well Supply Company.*)

water and other foreign materials. See "unaflo," page 212. As a rule, the pools are associated with gas and salt water, the gas lying on the top and the water on the bottom, so arranged by nature (Fig. 82). If the gas pocket happens to be pierced, a wet gaseous vapor will come to the surface. (It is from this so-called "casing-head gas" that casing-head gasoline

is obtained.) If an oil pocket is struck, the oil may be forced to the surface and result in a flowing well, or gusher.

In some instances, it is necessary to construct a dam around the wells to collect the oil from a gusher until it can be pumped out and piped away to the tanks. Sometimes gushers shoot into the air to great heights and are so terrific that large quantities of oil are lost before they can be gotten under control. It is reported that one such gusher in Mexico shot a column of oil into the air more than 600 feet, and it was several weeks before it was brought under control. When the well is not flowing, a charge of nitroglycerin is lowered to the bottom and exploded to loosen up the rocks so that the oil can flow more freely. This is also done in wells that have ceased to produce in paying quantities or have stopped altogether.

As many of the wells are not flowing, it is necessary to pump the oil to the surface (Fig. 84). If the wells are close enough together, it is customary to attach several pumps to one engine. This not only lessens the amount of machinery required but also makes it possible for one man to attend a larger number of units.

Recovering and Increasing Production of Oil Fields. It was early learned that only a part of the oil in any pool could be obtained by ordinary pumping. But so great was the supply and so eager were the operators to obtain large quantities on short notice that as soon as the cream, so to speak, was taken from one field, they moved on to the next. As new fields became

more costly and difficult to find, however, the question of reclaiming old wells became of special importance.

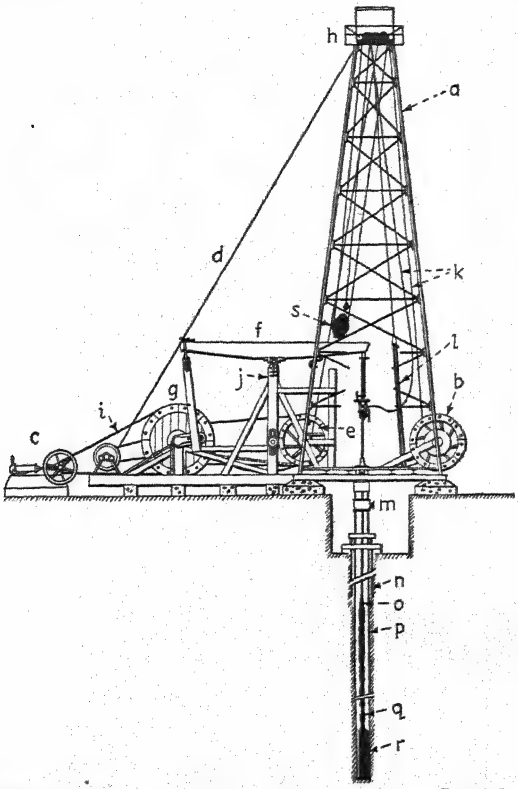

FIG. 84.—Cable-tool percussion drilling rig. *a*. Derrick. *b*. Bull wheel. *c*. Engine. *d*. Bail line. *e*. Calf wheel. *f*. Walking beam. *g*. Band wheel. *h*. Crown block. *i*. Belt. *j*. Samson post. *k*. Wire drilling line. *l*. Bailer. *m*. Master control gate valve. *n*. Casing, first string. *o*. Rope socket. *p*. Casing, second string. *q*. Stem. *r*. Bit. *s*. Travelling block. (*Courtesy of American Petroleum Institute.*)

This was especially true in Pennsylvania, the mother state of petroleum, where many of the wells had ceased to produce altogether and where the oil is of exceptionally high grade. Several methods of reclaiming

old fields have been tried, among the most successful being deeper drilling, flooding with water, introducing gas and air pressure, and mining. Deeper drilling is just what the name implies. The older wells did not go down very deep; consequently, only pools nearest the surface were tapped (Drake's well was 69 feet). By drilling deeper in the same section pools are often struck equal to if not greater than those worked in the beginning. A good example of this is seen in the Ventura field of California, where a well was drilled 2,250 feet deep in 1915. Oil was struck, but not in paying quantities, and the works were abandoned. In the same section eleven years later, wells were drilled 6,000 feet deep and were reported to be producing 60,000 barrels per day. At the present time wells are drilled over three miles deep.

As oil is always associated with sand, large quantities naturally adhere to the particles that cannot be secured by ordinary pumping. Flooding the wells with water often loosens the oil and causes it to flow, but the method is very expensive and is not used to any great extent. Recently, however, a method of drilling four wells, one at each corner of an area about 200 feet square, and a fifth well in the center, has been reported to recover old wells by flooding. Water is forced down the four corner wells and loosens the oil in the sands, causing it to flow to the center well, where it is pumped out. "Scrubbing" with gas, as it is called, has proved to be efficient in some cases. In this process natural gas—after its gasoline content has been removed—is pumped back into the wells

under high pressure and permeates all areas, loosening up the oil and causing it to flow freely. The process is called also "recycling," because natural gas is pumped back into the earth from which it was taken in the beginning. The practice has been known to increase the production of a single well more than 500 barrels per day.

Mining for Oil.—Special mining has been resorted to in some sections with more or less success, but it is still in the experimental stage and extremely costly. In this method a shaft is sunk several feet below the bottom of the oil sands, and cross-tunnels are excavated from the shaft under the pools. A large number of small wells are drilled upward through the roofs of the tunnels, allowing the oil literally to drain out. It is then caught and piped to the shaft and pumped to the surface.

Most methods of reclaiming oil in common use still leave a part in the sands. Recently, however, mining the sands and separating the oil from them afterward have been resorted to. The method is profitable only where the sands lie near the surface.

Many oil wells drilled in limestone formation are treated with hydrochloric acid to dissolve the rocks and thus help to increase the oil production. In some areas acidizing has replaced well shooting, and in others a combination of the two is practiced. In general, 1,000 gallons of 15 per cent hydrochloric acid will dissolve 11 cubic feet of limestone rock, but there seems to be no definite rule to give the quantity needed for a well.

Transporting Crude Oil.—In the early days of the industry, crude oil was transported largely in barrels. But as the production increased, this method became too slow and expensive. Railroad tank cars were next used, especially for long hauls. They can still be seen in sections where pipe lines have not been

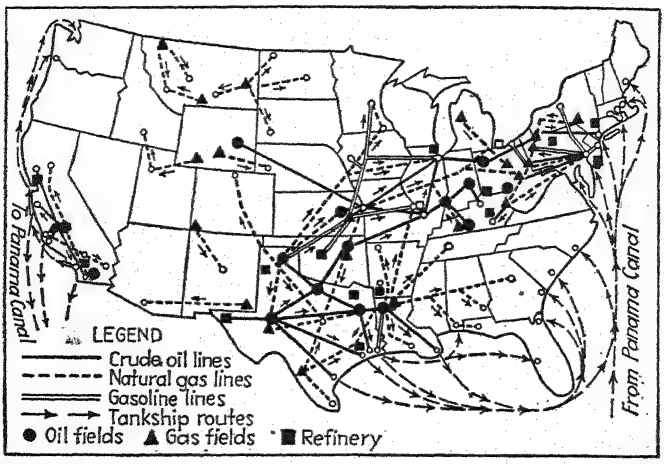

FIG. 85.—Petroleum industry's distribution system in the United States. (*Courtesy of American Petroleum Institute.*)

installed and where the nature of the country and conditions of the industry make their installation impracticable. The great bulk of the product, however, is transported in pipe lines. At the close of the Civil War there were only four miles of pipe lines in this country, located in western Pennsylvania.

In the United States at present there is a pipe-line system of more than 250,000 miles. About 112,000 miles are used in gathering and transporting crude oil. Some 3,500 miles are used in the transportation of gasoline. Upwards of

150,000 miles of natural gas pipe line also are in use. In recent years gasoline pipe lines have come into more general use because of their advantages of speed, safety, and economy in moving a commodity which can be moved by railroad only at premium rates and with some risk and waste.[1]

Great trunk lines fed by branches from the fields now connect the refineries at Galveston, Fort Worth, Tulsa, Baton Rouge, St. Louis, Chicago, Cleveland, Buffalo, Pittsburgh, Brooklyn, Bayonne, Philadelphia, Balti-

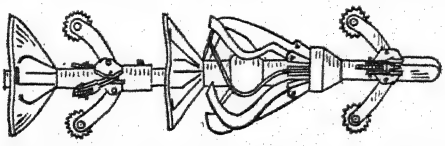

FIG. 86.—"Go-devil" for cleaning oil pipe lines. (*Courtesy of Oil Well Supply Company.*)

more, and other places (Fig. 85). A pipe-line system does not differ in its essentials from a large city water system, except that the trunk line is fed by the branches rather than supplying them. It is more nearly like a city sewer system, where the branches feed the main line.

Relay pumping stations are installed at proper intervals along the lines to keep the oil in motion. Every once in a while the pipes must be cleaned to keep them free from sediment. This is accomplished by a "go-devil," a circular, blunt instrument of practically the same diameter as the interior of the pipe (Fig. 86). The instrument is forced through the pipe from one station to another by pressure of the oil

[1] Courtesy of the American Petroleum Institute.

from behind; the pressure also gives the instrument a revolving motion, so that it scrapes the interior of the pipes clean as it passes along.

Refining.—It is not the purpose of this book to go into a discussion of the chemistry of crude-oil refining. In fact, the industry has developed into an extensive manufacturing business and requires a

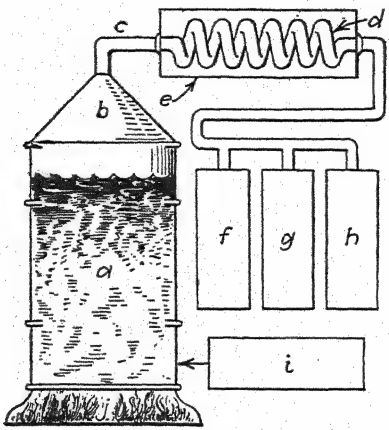

FIG. 87.—Apparatus illustrating simple distillation. *a.* Crude oil. *b.* Vapor space. *c.* Vapor line. *d.* Worm. *e.* Cooler. *f.* Gasoline. *g.* Kerosene. *h.* Gas oil. *i.* Fuel oil. (*Courtesy of American Petroleum Institute.*)

separate treatise. However, a few of the more common phases of the subject can be mentioned at this time to give the students a general idea of the sources of some of our more common petroleum commodities.

Among the more important products are gasoline, kerosene, fuel oil, lubricants, solvents, wax, asphalt, and coke. In the earlier days of the industry petroleum refining consisted primarily of simple distillation, sometimes with the use of a vacuum. Kerosene was

the principal product sought, since there was very little use or market for gasoline at that time. In fact, the distillates were often exposed to the air to allow the gasoline to evaporate to separate out the kerosene. The heavier materials were further distilled with steam and subsequently treated to remove wax and other substances from the lubricating oils. But with the advent of the automobile and other machines using gas engines, the demand for gasoline rapidly increased and soon far outdistanced that for kerosene.

Up to about 1914, from 15 to 20 per cent of gasoline was considered a fair yield from the average grade of crude oil. But since that time cracking and other processes have been developed that increase the production up to as high as 90 per cent. Cracking consists primarily in redistilling heavier oils under greater pressure and at high temperatures. Catalytic agents and other compounds are also sometimes used.

A recent development in the production of gasoline from fixed gases, both natural and still gas, is called "polymerization," which is the reverse chemically from the reactions involved in cracking. In the process the smaller molecules of the fixed gas are combined and formed into larger ones for a gas that can be condensed into a liquid. A high-grade gasoline is obtained by the process.

In addition to being obtained directly from crude oil, gasoline is also obtained from natural gas—both "casing-head" and "wet-gas" wells. If these gases are compressed and cooled, a large percentage can be condensed. The gases can also be absorbed by an oil

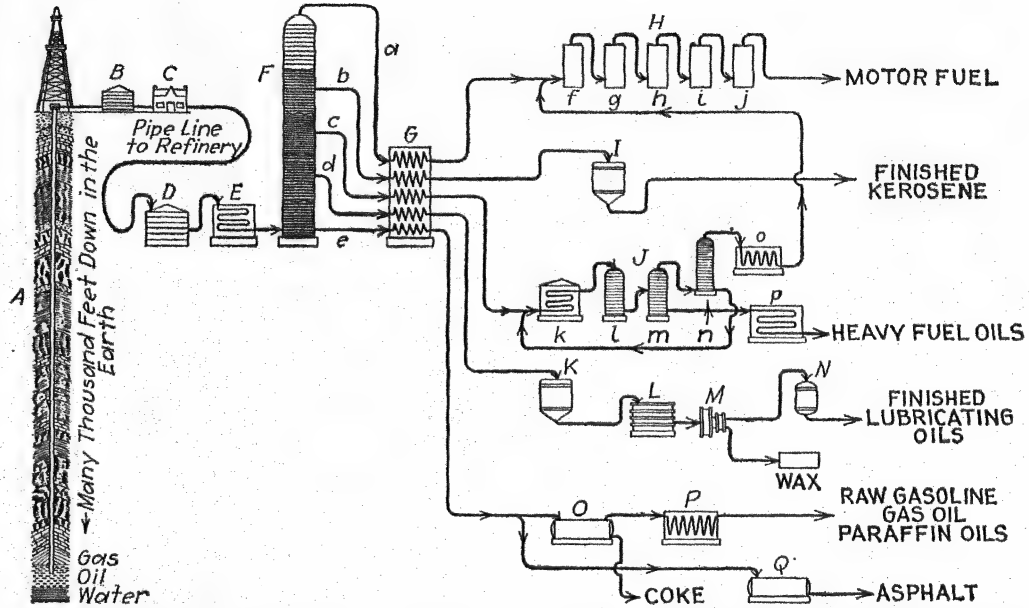

FIG. 88.—Flow chart of petroleum distillation. *A*. Oil well. *B*. Field storage. *C*. Pumping station. *D*. Refinery storage. *E*. Pipe still. *F*. Bubble or fractioning tower. *G*. Condenser. *H*. Continuous purifying system. *I*. Agitator. *J*. Cracking unit. *K*. Agitator. *L*. Chiller. *M*. Filter press. *N*. Clay percolator. *O*. Coke still. *P*. Condenser. *Q*. Asphalt still. *a*. Raw gasoline. *b*. Raw kerosene. *c*. Gas oil. *d*. Lube distillate. *e*. Heavy bottoms. *f*. Acid. *g*. Water. *h*. Caustic. *i*. Doctor. *j*. Water. *k*. Pipe heater. *l*. Reaction chamber. *m*. Evaporator. *n*. Bubble tower. *o*. Condenser. (*Courtesy of American Petroleum Institute.*)

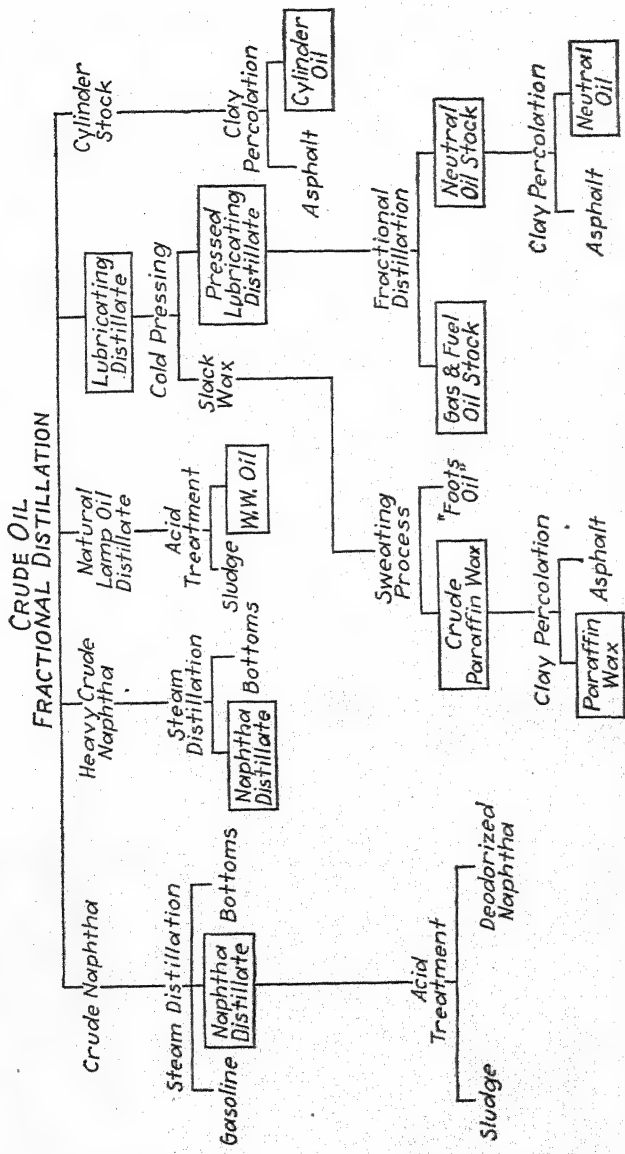

FIG. 89.—(Courtesy of Standard Oil Company of New York.)

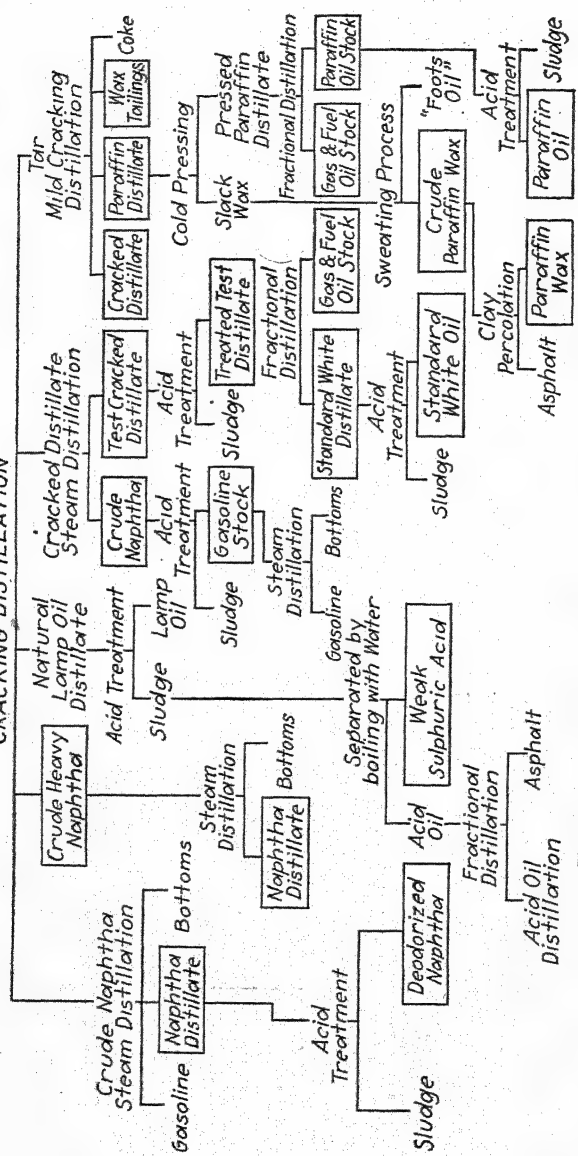

FIG. 90.—(*Courtesy of Standard Oil Company of New York.*)

and afterwards recovered as gasoline by distillation. Such products are known as "natural gasoline" and comprise quite a large percentage of the motor fuel manufactured in the United States. Other processes for the refining of crude oil are constantly being developed, but this subject leads far into the field of chemistry and cannot be discussed in this connection.

For a long time illuminating oils and fuel oils have been distilled from bituminous coal, but only in recent years has the subject received special attention in this country. Several processes for the purpose have been developed, among the most promising of them being the so-called "Bergius patent for synthetic oils." "Bituminous coal is powdered and mixed with tar to make a paste which is heated to about 400°C. under high pressure. A heavy oil is distilled off, which in turn is redistilled into fractional products."[1] According to a report of the Department of Commerce 300 pounds of gasoline, 400 pounds of diesel oil, 120 pounds of lubricating oil, and 160 pounds of fuel oil can be obtained from a ton of coal by the process. It is also known that valuable oils can be obtained from the distillation of lignite.

Shale Oil.—In addition to oil pools we have enormous deposits of oil shale, especially in the West, which can produce billions of barrels of oil when it is needed. Experiments are already being made in this country in extracting oil from shale. (At the present time, however, oil on a commercial scale is not produced in this

[1] Courtesy of Isaac F. Marcosson, in *The Saturday Evening Post.*

country from this source.) The following quotation[1] describes a process developed in one shale-oil plant in California:

The process employs a cylindrical retort of forty tons capacity, having an enclosed grate at the bottom, connected with a suction fan, which creates a down draught within the retort, passing out through the grate and a set of condenser tubes and scrubbers. The manner of operation is as follows: The generator is filled with shale crushed to a maximum size of two inches. A fire is kindled on the top of the charge by means of wood fuel and about a gallon of crude oil. The suction fan is turned on, drawing the heat of this combustion down through the charge of shale. In about three minutes the shale at the top of the charge is burning strongly, and the cover of the generator is then closed so that only enough air is admitted to support slow combustion, which is allowed to continue only on the fixed carbon in the shale.

The volatile matter is carried off at a comparatively low temperature by the hot flue gases and is caught in passing through the water-cooled condensers and scrubbers. A part of this flue gas is mixed with the air entering the generator and serves to increase the volume of gases passing through the charge without accelerating the combustion. As the distillation proceeds, the fire zone gradually moves down through the charge, driving off the oil some distance in advance. A sudden rise of temperature at the grate indicates completion of the process. The blower is stopped, and the entire grate is rolled back by means of a motor-operated screw allowing the spent shale to drop clear of the

[1] Department of Commerce, Bureau of Mines, *House Document* 643, Part 2, p. 376.

generator while hot. The grate is then returned to position and is ready for the succeeding charge. The cycle requires about twenty-four hours. It should be noticed that the shale itself furnishes the fuel for the process; there is no external heating required; the only moving part during distillation is the suction fan that handles the cooled gases from the condenser; the grate and its mechanism are not subject to excess heat or wear by abrasion from the shale.

The percentage of oil recovered from this process is said to be about 36 barrels to a 40-ton charge of shale, or about ⅞ barrel per ton.

So long as an abundance of crude oil can be obtained from natural pools it is not likely that the shale-oil industry will develop to any great extent in this country. But when the natural pools begin to show exhaustion, we shall still have the enormous shale deposits for a reserve supply to fall back on.

Petroleum Terms

asphalt base—The name given to petroleum that contains asphalt remaining as a residue in distillation.

casing—A pipe lowered into an oil well to keep out gravel and other matter.

casing-head gasoline—Gasoline obtained from saturated gas from an oil well.

coal oil—Oil obtained from the distillation of bituminous coal.

cracking—Redistilling heavy oils under pressure to obtain a larger percentage of gasoline.

crude oil—Raw petroleum as it comes from the earth.

divining rod—A wooden rod or branch supposed to have special qualities for detecting mineral oil or water in the earth.

Drake's well—The first successful oil well drilled in this country, drilled by Edwin Drake at Titusville, Pa., in 1859.

gas pocket—A cavity in the rocks containing gas, generally above an oil pocket.

geophysics—A study of the rocks of the earth by the application of scientific elements, as electricity, gravity, sound, etc.

go-devil—(1) A special spiral apparatus that is sent through a pipe line to clean out the sediment. (2) An iron rod dropped down a well to explode a charge of nitroglycerin.

gusher—A flowing well caused by the pressure of the gas below.

hydrocarbon—A compound principally of hydrogen and carbon.

natural gasoline—Gasoline extracted from natural gas.

nitroglycerin—A powerful explosive used for shooting an oil well.

oil pocket—A cavity in the rocks containing oil.

oil refinery—A plant where petroleum is distilled and otherwise refined.

oil sand—A sandstone deposit in an oil region.

paraffin base—A term applied to petroleum leaving paraffin as a residue when it is distilled and cold pressed.

paraffin wax—A wax substance obtained by pressing the heavy distillate of petroleum in a very low temperature.

pipe line—A line of pipe, generally for transporting crude oil; also for gasoline and other oils.

pumping station (relay station)—A station on a pipe line supplied with a pump for forcing the crude oil along from one station to the next.

relay station—See Pumping station.

shooting a well—Exploding a charge of nitroglycerin at the bottom of a well to make the oil flow freely.

storage tanks—Large circular steel tanks for storing oil, located near the well or near the refineries.

tank cars—Railroad cars equipped with large steel tanks for transporting crude oil.

tanker—A special boat or ship for transporting oil in bulk.

wet-gas wells—Gas wells that produce a gas from which gasoline can be obtained but which do not produce crude oil.

Petroleum Questions

Group I

1. Where does the name "petroleum" come from?

2. What evidence have we that petroleum was used in very early times?

3. What special difficulty did parties drilling for salt in the Ohio Valley encounter in the early history of the country?

4. For what purpose were bituminous substances used in ancient Egypt?

5. By whom, in what year, and at what place was the first successful oil well drilled in this country?

6. What is considered the beginning of the oil industry in this country?

7. In what special way is the memory of Edwin Drake's efforts perpetuated?

8. What use did the Indians make of crude oil? What was it called?

9. What effect did the spread of the news of Drake's well have on the country?

10. In what way do the vibrations of rocks indicate that oil might be found in a locality?

11. How does electricity aid in detecting oil sands in the earth?

12. What do the following terms bring to your mind: paraffin base, asphalt base, mixed base?

13. Explain what causes a gusher.

14. Give reasons for shooting a well. What explosive is used for shooting?

15. About how many miles of pipe line are in the United States at the present time?

Group II

16. What is the advantage of using a hollow drill when prospecting for oil?

17. What would the fact that crude oil was found with the brine of salt wells of the Ohio Valley seem to indicate?

18. What is meant by the gold rush?

19. How can we account for petroleum pools being distributed widely in the world?

20. What is meant by the relative position of a country in respect to crude-oil production?

21. What is meant by the saying "Drilling for oil is more or less of a gamble"?

22. When oil, water, and gas are found together in the earth, explain their relative positions.

23. What is meant by saying "The oil industry is the basis of other industries"?

24. Why are pipe lines used more for the transportation of crude oil than for gasoline and other crude-oil products?

25. How would you determine how many gallons of oil are required to fill a certain section of pipe line? Give a concrete example.

26. What is meant by fractional distillation?

27. What is meant by an aerial condenser? Explain how it works.

28. Why are storage tanks located both at the oil fields and at the refineries?

29. What is meant by petroleum coke? How is it obtained?

30. What relation has the oil industry to the automobile and the airplane industries?

31. Give reasons for locating refineries near large cities.

ASPHALT

Historical Uses.—Asphalt is a black mineral substance, also known as "mineral pitch" or "mineral tar." It ranges in consistency from a sticky, viscous liquid to a hard, brittle solid. It was known and used in very early times as a mortar for building construction and other purposes. Noah is said to have pitched the ark within and without, the pitch being probably bitumin or asphalt. We also find evidence of its use

in the foundations of the pyramids; and it was a common practice among the Egyptians to embalm their dead with asphalt, as is seen in the mummies preserved in museums. They also used it for floors, coatings for cisterns, roofing, and in other places where a waterproofing material was required.

There are several kinds of asphalt on the market, among the more common of them being Trinidad asphalt, Bermudez asphalt, gilsonite, rock asphalt, and petroleum asphalt.

Trinidad Asphalt.—Trinidad asphalt is the most important of this group and is obtained from the so-called "pitch lake" on the island of Trinidad, about 700 miles from the equator and 2,000 miles from New York. The lake is roughly circular in form and covers an area of about 114 acres. It is about 175 feet deep in places, but its depth cannot be sounded in other places because the tools twist off with the motion of the asphalt before they reach the bottom. The surface is about 135 feet above sea level, which makes it very convenient to transport the asphalt to the docks by the aid of gravity.

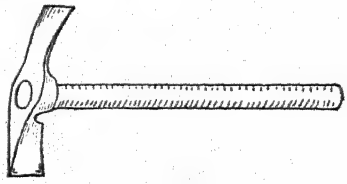

Fig. 91.—Mattock.

The crude pitch is dug out by hand with a tool called a "mattock" (Fig. 91), loaded into bucket cars, and transported to the edge of the lake, where the buckets are attached to a cable which conveys them down to the ships (Fig. 92). The cable carrier is

arranged in the form of an endless belt running over pulleys; and the full buckets attached to one strand of the belt in passing down the incline help to pull the empty buckets back. As each day's quota is dug out, the cavity fills in again overnight, leaving the surface practically smooth the next morning.

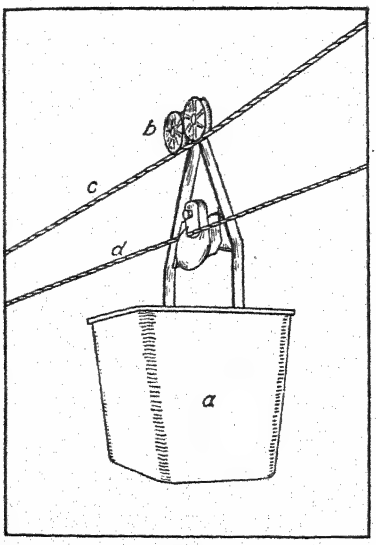

FIG. 92.—Cableway transportation line. *a*. Bucket. *b*. Carrier. *c*. Cable. *d*. Traction rope.

This action seems to be due to the plastic asphalt seeking its own level, much as stiff dough fills in dents made in the surface by the baker. The whole lake has a slow folding motion that can be discerned only by the relative movements of sticks or other objects on the surface. (If the sticks are placed in line, in a short time they will be seen to have changed their relative positions.) There are several

floating islands on the lake which move about in the same manner.

A considerable percentage of the asphalt is refined at the island; the remainder is loaded into the holds of vessels and shipped to its destination in crude form. The refining process consists largely in removing the water and other impurities by boiling the crude pitch in a tank supplied with steam coils. Sticks and other foreign matter rise to the top and are easily removed. Trinidad asphalt contains about 40 per cent of bitumin and 28 per cent of water; the remainder is mineral and organic matter.

Bermudez Asphalt.—The next important deposit of asphalt is in Bermudez on the northern coast of Venezuela about 105 miles from Trinidad. Some authorities believe that the two deposits are connected, but this has never been proved. The Bermudez lake covers an area of about 1,000 acres, but it is not so deep as the Trinidad lake, ranging in depth from 2 to 10 feet. Neither is the pitch so uniform in consistency. In some places springs of soft asphalt are constantly flowing, while in other places it is hard and brittle and must be blasted out to be obtained. Bermudez asphalt contains about 66 per cent of bitumin and 31 per cent of water.

Several Uses.—The uses of asphalt are very common, among them being binders for roads, streets, and paving bricks, waterproofing, paints, varnishes, cement, paper, shingles, pipe coverings, insulating materials, flooring, walls, rubber compounding, and saturating materials.

Asphalt paper is produced by saturating felt paper with hot asphalt and rolling it down between heated rolls; and asphalt shingles are produced by preparing the paper practically in the same manner and afterward coating the surface with granulated slate and again rolling it down and cutting the shingles to size.

Gilsonite.—Gilsonite is a tarry, coal-like asphalt sometimes known as "mineral rubber." It is very brittle and breaks with a rough, conchoidal fracture. The main deposits in this country are along the border line between Colorado and Utah. Its principal uses are in asphaltum paints and varnishes and as a compounding material for rubber.

Rock Asphalt.—So-called "rock asphalt" is porous rock containing more or less asphalt. Sometimes the asphalt is found in pockets or veins, and in other instances it is disseminated throughout the whole rock structure. The principal asphaltic limestone deposits are in Uvalde County, Texas, where it has been mined and used locally to a considerable extent for street and road construction. The principal asphaltic sandstone rock deposits are in Kentucky. It also appears in Oklahoma and a few other states. When asphaltic rock is used for road or street construction it is generally crushed fine and heated and then tamped and rolled down hard. The bitumin acts as a natural binder for the other materials and renders the surface waterproof.

Petroleum Asphalt.—As has been suggested, petroleum is classified as asphaltic or paraffin base. When petroleum with an asphaltic base is distilled, nearly

pure asphalt remains as residue. This is used largely in road surfacing, waterproofing, and for many other purposes where natural asphalt would be used. It is sometimes mixed with the natural product.

Asphalt Terms

asphalt—A brown-black bituminous substance.

asphalt rock—Natural rock containing asphalt.

Bermudez—A state in the northeastern part of Venezuela containing a large deposit or lake of asphalt.

conchoidal—Shell-like, or breaking with a shell-like fracture.

crude asphalt (crude pitch)—Raw asphalt as it comes from the lake.

gilsonite—A brittle form of asphalt used more especially for paints and varnishes and as a compound for rubber.

manjak—A high grade of asphalt used largely in paints and varnishes.

martic—A mixture of bituminous matter, such as asphalt, and some foreign material, such as sand.

mattock—A picklike tool used for digging asphalt.

mineral rubber—See Gilsonite.

petroleum asphalt—Asphaltic substance left as a residue when crude petroleum with asphaltic base is distilled.

pitch lake—The asphalt lake on the island of Trinidad.

Trinidad—An island off the northern coast of South America in the Caribbean Sea.

Asphalt Questions

Group I

1. What evidence have we that asphalt was known and used in very early times?

2. Where are the main asphalt deposits found?

3. Describe the Trinidad asphalt lake as to its shape, size, depth, and location.

4. Explain how Trinidad asphalt is mined.

5. How is crude asphalt refined?

6. What is rock asphalt?

7. What is gilsonite? Give two special uses for gilsonite.

8. What is meant by Bermudez asphalt?

9. What is meant by sandstone bituminous rock? What is this rock used for? Where are the principal deposits?

10. How is it possible to determine that the Trinidad asphalt lake is in motion?

11. Name some of the most common uses for asphalt.

GROUP II

12. In what form is asphalt generally shipped from Trinidad?

13. What qualities does asphalt possess that make it valuable for paving?

14. What particular use has asphalt in the construction of cellars, subways, and other underground construction?

ASBESTOS

Historical Sketch.—Asbestos is a fibrous mineral. Generally speaking, it is a silicate of magnesia, but it also contains other ingredients, as lime, iron, alumina, and water. The name is derived from the ancient Greek language and literally means inextinguishable, although the substance is incombustible.

It was known and used by the ancients in a variety of ways. Often the corpses of kings and heroes were wrapped in asbestos blankets to keep their ashes separate from those of the crematory fires. It is stated that the wick of the eternal lamp in the temple at Athens was of "crystalline flax." Charlemagne is said to have astonished his dinner guests by using a table cloth of "cotton stone" which he threw into the fire after the meal for cleaning, afterward removing

it uninjured. In spite of the fact that asbestos was known in very early times, its real importance was not appreciated until the latter part of the past century. Since that time, however, its applications have greatly extended, and at the present time it can be considered one of the indispensable materials of industry.

Nature.—Asbestos varies in color from snowy white through shades of blue, green, yellow, pink, and brown. Two major varieties are recognized: chrysotile and amphibole, the main difference between them being the length of the fiber and the amount of water contained. Chrysotile has the longer fiber, is more flexible, and is consequently better suited for spinning and weaving, but the amphibole variety can stand much higher temperature and is a better protection against fire.

Deposits.—The principal workable deposits at the present time are in the Province of Quebec, Canada, in the vicinity of Black Lake, from which the largest percentage of the chrysotile variety is obtained. It is also mined to a greater or lesser extent in Arizona, Massachusetts, Connecticut, Maryland, Virginia, North Carolina, South Carolina, Vermont, Georgia, Alabama, and Pennsylvania. The U.S.S.R., Italy, and South Africa also produce considerable quantities, but as a rule the fiber is not so well suited for spinning and weaving as that found in Canada.

Quarrying and Fiberizing.—The fiber is found in veins (generally not over three inches thick) embedded in serpentine rock and is mined for the most part by

the open-pit methods. First, a large quantity of the rock is blasted loose at one shooting, and the smaller pieces are sorted and cobbed to secure as much fiber as possible before the larger pieces are taken from the quarry.

Cobbing consists of breaking the fibrous pieces from the worthless rock and is done by hand with a cobbing hammer. The larger rocks are removed and crushed by machinery, and the fiber is separated from the other material by screens through which an upward suction of air lifts and conveys away the powdered rock and the smaller pieces of fiber. The fibers are next sorted by machines according to length and graded as No. 1 for spinning and weaving, No. 2 for asbestos paper and wall board, and No. 3 for cements.

Spinning and weaving asbestos fabrics do not differ in their essentials from methods employed for cotton and other fibers, except that the fibers are smooth and slip on each other easily, making it impossible to produce a strong yarn unless it is reinforced with wire or other material.

Uses.—The uses of asbestos are too well known to need any extensive explanation here. Among the more common are theater curtains, clothing, gloves and shoes for firemen and electricians, rope, sheets for packing, paper, wall board, pipe, boiler, and furnace coverings, paints, shingles, and cement. Its principal qualities are its resistance to heat combined with the ease with which it can be worked into various forms and its slow thermal conductivity.

Asbestos Terms

amphibole—A short-fiber type of asbestos.

Black Lake—A lake in Quebec, Canada, in the vicinity of which are important asbestos mines.

chrysotile—Long-fiber asbestos.

cobbing—Breaking the asbestos fiber loose from the rock by hand.

cyclone—A circular blowing apparatus for separating the fibers from the rock after they have been loosened by fiberizing.

fiber—The smallest single strands of asbestos or other fibrous materials.

fiberizing—Beating the asbestos rock into fiber, or separating the fibers.

incombustible—Applies to substances that will not burn.

magnesia—Magnesium oxide, a white earthy substance sometimes powdered and mixed with asbestos and used for pipe coverings to conserve heat.

tailings—The waste rock after the asbestos fiber has been removed.

Thetford—A town in Quebec, Canada, noted for its asbestos mines.

Asbestos Questions

Group I

1. What special quality makes asbestos valuable?

2. What does the term "asbestos" mean?

3. Name the two principal varieties of asbestos, and give the special quality of each.

4. In what condition is asbestos found in the deposits?

5. Where are some of the principal asbestos deposits?

6. What is meant by tailings?

7. What is meant by fiberizing?

8. How is crude asbestos graded?

9. Why is it impossible to make asbestos yarn that is strong without the use of wire or other reinforcing material?

10. How is asbestos cloth made? Name some of the most important articles made from asbestos cloth. Why is the material especially good for these articles?

11. What material is sometimes mixed with asbestos to use as cement for pipe covering?

Group II

12. Why must cobbing be done by hand?

13. How does asbestos resemble cotton?

14. Of what special value is asbestos paint?

15. What is asbestos board? When would this be used ordinarily?

16. Why is asbestos especially good for oil-stove wicks?

17. Why is asbestos especially good for automobile-brake linings?

LIME, CEMENT, CONCRETE, AND PLASTER

Lime

Lime is the product resulting from the calcination, or burning, of natural lime rock (calcium carbonate). It was probably first discovered by savages from pieces of burned lime rock left where a camp fire had been. After a passing shower some of this rock had dissolved and formed a powder that would harden after being mixed with water and sand and dried. It must have been discovered that this new material was more durable and better adapted for plastering up the cracks in huts than common mud.

Historical Sketch.—It is reasonable to believe that the use of lime mortar spread very rapidly because of its great utility. We find it not only in the most ancient ruins of Europe, Asia, and Africa but also in those of Mexico, Peru, and other countries. As one writer puts it: "Plastering is one of the earliest instances of man's power of inductive reasoning . . .

at first like birds and beavers with mud; but they soon found out a more lasting and comfortable method," etc.

The monuments of Egypt furnish, without doubt, the most ancient and remarkable examples of the use of lime mortars. In many instances they have practically the same composition as those used at the present time. The Greeks used lime in their buildings at a very early period. Often their houses were finished in plaster that compared very favorably in whiteness and polish to Parian marble. The Romans learned the art of plastering from the Greeks and spread it to their colonies. It was practiced in England at a very early period, and in 1501 "The Plasterer's Company" was formed in London to do all kinds of artistic plastering work.

The knowledge of the manufacture and use of lime naturally came to America with the first settlers. Wherever colonies were planted, there lime kilns were apt to be built to furnish mortar for walls, chimneys, and underpinnings. The result was that lime burning became quite a common occupation. From limestone gathered on their own fields farmers often set up kilns and burned lime as a side line.

Early Lime Kilns.—For many years all of the lime used in this country was produced in crude stone kilns consisting of single shafts, or pits, open at the top for charging and at the bottom for firing and drawing the lime (Fig. 93). The following is a description of an early lime kiln: "The kiln is built of refractory rock lined with clay and laid outside with mortar 15 feet high, 15 feet wide, and 5 feet back. Arches, middle,

5 feet high; side, 3½ feet high." This kiln had a capacity of 45 tons of lime per burning and consumed cords of wood. When possible these kilns were built in the sides of hills to facilitate reaching the top for easier charging. Although the great bulk of lime produced in this country is burned in plants equipped

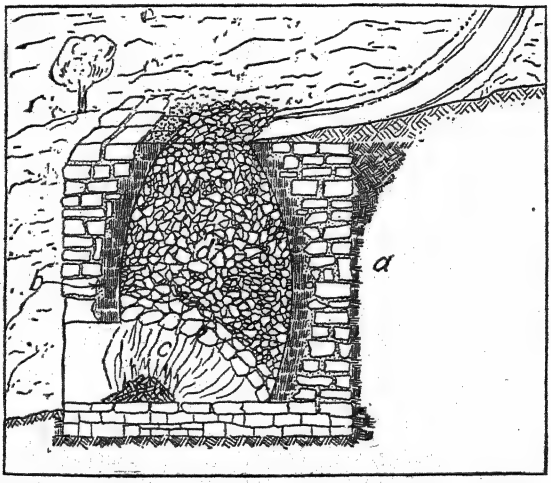

FIG. 93.—Early stone lime kiln. *a.* Rough masonry. *b.* Refractory lining. *c.* Fire. *d.* Lime rock.

with modern apparatus, the old type of stone kilns can still be seen in operation in a few remote districts.

Modern Type of Lime Kilns.—There are two general types of modern lime kilns in use: the intermittent and the continuous. The continuous type is divided into vertical and rotary. The most common modern type of vertical kiln consists of a steel shell lined with fire brick and having two or more fire boxes in the sides near the bottom for burning (Fig. 94). The special advantages of this type are that coal, wood, gas, or

oil can be used for fuel and that the lime is not discolored by coming into contact with the ashes or other products of combustion. A considerable quantity of lime is still burned in intermittent vertical kilns which do not have the exterior fire boxes but in which the fuel (coal) is mixed in alternate layers with the limestone. These kilns are known as "mixed-feed" kilns. The type is economical, but the lime becomes more or less contaminated by contact with the burning fuel. In recent years rotary kilns have been developed for burning lime. They are practically the same in construction and operation as those used for Portland cement described later. They are proving economical and are gradually taking the place of upright kilns.

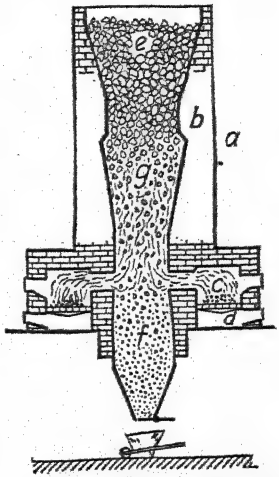

FIG. 94.—Modern upright lime kiln. *a*. Steel shell. *b*. Refractory lining. *c*. Furnace. *d*. Ash pit. *e*. Charge of limestone. *f*. Lime. *g*. Calcining chamber.

Quicklime.—There are three general kinds of lime: quicklime, hydrated lime, and hydraulic lime. Quicklime is the first product from the limestone and is the raw material from which hydrated lime is obtained. In its production the lime rock is sorted and broken into pieces of suitable size for burning. It is then screened and charged into the kilns. The flames and heat travel through the mass, driving off the water and carbon dioxide. As the finished product drops

to the receiving hopper, it is drawn and cooled and is ready for storing. If the continuous type of kiln is used, fresh limestone is charged in as the finished lime is drawn, thus keeping the process continuous. Quicklime when slaked (dissolved in water) generates great heat, and care must be exercised in storing to prevent fire from accidental slaking.

Hydrated Lime.—A large percentage of quicklime is converted into hydrated lime by treating it with just enough water for complete hydration. This is done by agitating the granulated quicklime in a hydrator (a closed vessel) in the presence of water. The product is a fine, white, airy powder about three times the bulk of the original quicklime. The uses of hydrated lime are practically the same as those of quicklime. Because of its prehydration and powdered form, it is always ready for use and is consequently more convenient than the former.

Hydraulic Lime.—Hydraulic lime is produced from an impure limestone and will harden under water. It is not manufactured or used to any great extent in this country.

Cement

Historical.—Cements are closely allied to lime and are taking its place in mortars, especially when strength is an important consideration. Since times of remotest history they have been used in one form or another. Remains of structures as hard as rocks involving cements are still found in Egypt and other countries. The famous Appian Way and the great

aqueduct systems built by the Romans are still in a remarkable state of preservation and are monuments to the durability of the cements used in their construction. The ruins of ancient Carthage also disclose structures involving the use of cement on a scale that astonishes modern engineers.

Natural Cements.—Natural cement as we know it today is produced by calcining and pulverizing argillaceous, or clay, limestone (natural cement rock) at a temperature just below the fusing point (from 1800 to 2300°F.). In this country the industry began in 1818 when Canvass White, an engineer on the construction of the Erie Canal, discovered a natural cement rock in central New York. About 1825 important deposits of natural cement rock were also discovered at Rosendale, Ulster County, in the state of New York. For many years the product of these deposits was the most important natural cement in the country. It was the standard by which all other natural cements were gaged. In fact, in time all other brands of natural cement came to be known as "Rosendale" cement. Canal construction in other parts of the country disclosed other important natural cement rock deposits and also created a demand for the product. Notable among these deposits were the ones at James River in Virginia, at Utica, Ill., and in eastern Pennsylvania.

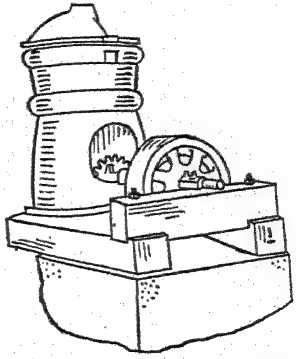

FIG. 95.—Early rock crusher.

For many years natural cements produced at Akron and Howe's Cave, N. Y., were well-known brands on the market. After the advent of Portland cement, however, the demand for natural cements rapidly decreased until at the present time comparatively little of the product is manufactured.

Portland Cement. Historical Sketch.—With the decline of the Roman empire the art of cement making seemed to have been lost and did not revive again until about the middle of the eighteenth century. In 1756 John Smeaton, an Englishman, discovered an impure, claylike limestone, which, when burned at a certain temperature and pulverized, would harden under water. Several attempts were made to produce this cement on a commercial scale but with little success. In 1824 Joseph Aspden, another Englishman, took out a patent for an improved hydraulic cement to which he gave the name "Portland" cement, because of its resemblance to building stones found on the island of Portland off the southern coast of England. This was the real beginning of the modern Portland cement industry.

In this country Portland cement was first produced by David Saylor at Coplay, Pa., in 1872. The first large projects to use the material were the jetties at the mouth of the Mississippi River and the Drexel Institute in Philadelphia. At the time of the centennial in 1876 only a few small Portland cement mills existed in the country. At the present time over 150 large plants are in operation in the eastern and western parts of the United States. (The center

of the industry at the present time is in eastern Pennsylvania.)

Raw Materials.—The scientific definition for Portland cement as used by the American Cement Manufacturers' Association is as follows:

Portland cement is the product obtained by calcining to incipient fusion an intimate and properly proportioned mix-

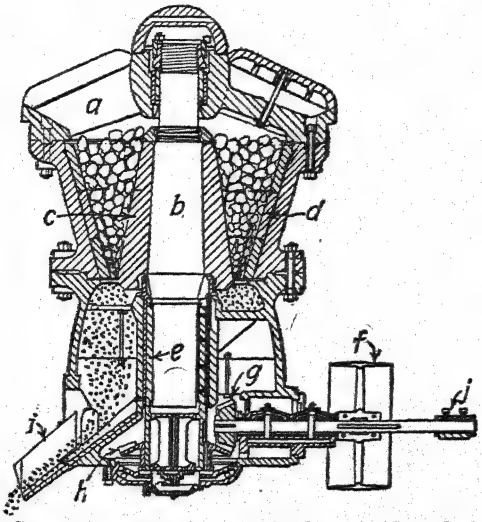

FIG. 96.—Gyratory rock crusher. *a.* Spider. *b.* Main shaft. *c.* Head. *d.* Concaves. *e.* Eccentric. *f.* Pulley. *g.* Bevel pinion. *h.* Bevel gear. *i.* Spout. *j.* Bearing. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

ture of argillaceous and calcareous materials, without the addition of anything subsequent to calcination excepting water and calcined or uncalcined gypsum.

Briefly stated, this means that clay or shale is mixed with limestone or cement rock in proper proportions thoroughly pulverized, and then fused to a clinker, which, in turn, is mixed with gypsum (3 to

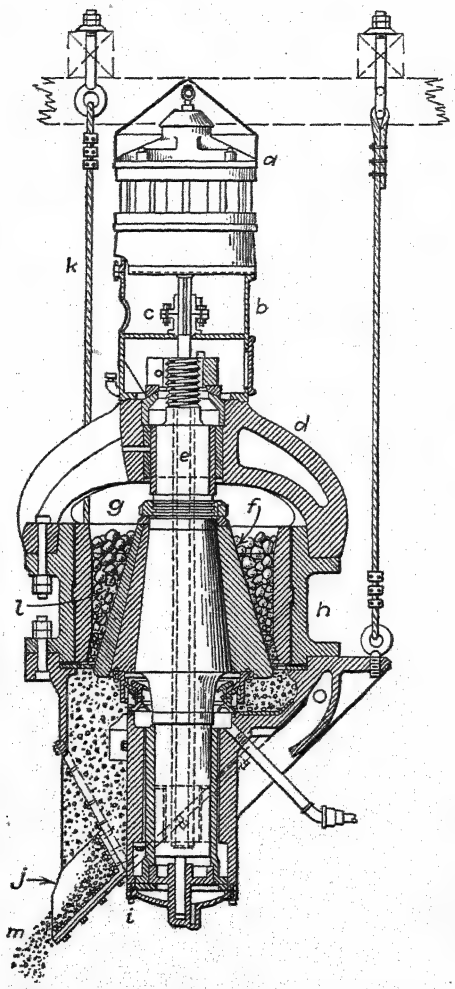

FIG. 97.—Modern rock crusher. *a*. Motor. *b*. Motor support. *c*. Coupling. *d*. Spider. *e*. Main shaft. *f*. Chilled iron head. *g*. Steel mantle. *h*. Top shell. *i*. Eccentric driving plate. *j*. Spout. *k*. Cable. *l*. Stone. *m*. Cracked stone. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

3½ per cent) to prevent too rapid setting and is again pulverized. No requirements are given for special kinds of raw materials, but the finished product must have a definite chemical composition to meet certain standards. The most common raw materials are cement rock, limestone, shale, clay, and marl. The wide range of raw materials available makes it possible to manufacture the product in nearly all parts of the country.

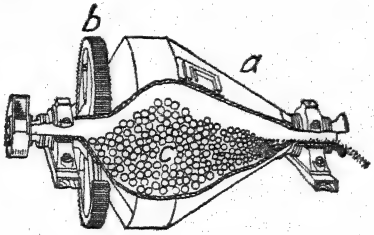

FIG. 98.—Hardinge conical ball mill. *a*. Shell. *b*. Gear. *c*. Balls and material. (*Courtesy of Hardinge Company, Inc.*)

Dry Process.—There are two general processes in common use for making Portland cement, the dry process and the wet process, the only practical difference being that in one instance the raw materials are prepared for burning dry, and in the other they are prepared for burning wet. In the dry process the cement and limestone are crushed in some form of rock crusher (Figs. 96, 97). They are then thoroughly dried and put through ball mills for further grinding. These mills consist of steel drums or cylinders about 8 feet in diameter and 6 feet long and partly filled with steel balls. Curved steel wearing plates are bolted to the interior of the rim of the drum like steps. The raw materials are fed into the drum

and, when ground, pass out through screens in the rim behind the plates. The mill makes about twenty-five revolutions per minute; and, as it runs, the balls are

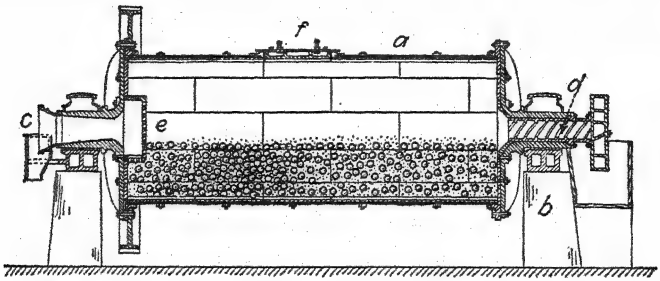

FIG. 99.—Tube mill. *a.* Shell. *b.* Foundation. *c.* Discharge hopper. *d.* Spiral feed. *e.* Screen. *f.* Manhole. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

carried up on the ascending side and drop off and pulverize the material by impact. Sometimes conical mills are used (Fig. 98). After the ball mills, the

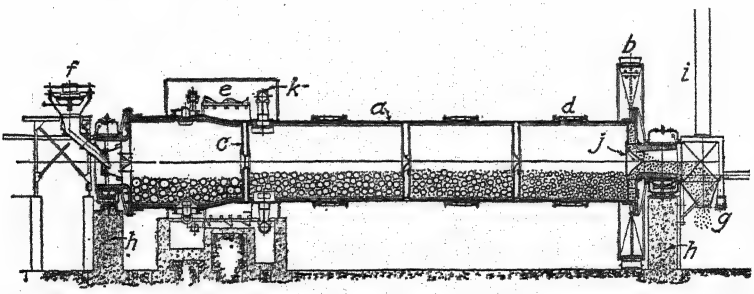

FIG. 100.—Compeb mill. *a.* Steel shell. *b.* Driving gear. *c.* Partition. *d.* Manhole. *e.* Screen. *f.* Feeder. *g.* Discharge hopper. *h.* Foundation. *i.* Ventilating pipe. *j.* Discharge screen. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

materials are sent through tube mills for finer pulverizing. These mills are similar to the ball mills except that they are longer and that the balls used are smaller

and grind finer (Fig. 99). The tube mills often grind to a fineness that will pass through a mesh of more than 200 to an inch, or so fine that water will not pass through it under ordinary pressure. Formerly flint pebbles were used in these mills for grinding, but in recent years the tendency is to substitute steel balls because of their greater efficiency and durability. In most modern plants it has become the practice to eliminate extra grinding machinery by using combination mills [so-called "compeb mills" (Fig. 100)]. The materials pass automatically from one compartment to the next, each one grinding a little finer until the desired results are obtained.

After the raw materials are sufficiently pulverized they are thoroughly mixed with automatic mixers in blending bins. This part of the process is of extreme importance and must be under control of an expert chemist at all times, because a slight variation in proportioning might seriously affect the quality of the cement.

Up to about 1895 all Portland cement was burned in upright, dome kilns, structures built much on the same order as vertical kilns for lime. The raw mixture was made into cakes and charged into the kilns in alternate layers with coal or coke. After burning, the kilns were allowed to cool, and the resulting clinker was removed and pulverized. The process was slow and difficult, and the cement costly. In recent years, however, rotary types of kilns have entirely displaced the vertical type, with the result that the cement can be made so comparatively cheap that it has become the

universal bonding material for all kinds of concrete and masonry construction.

A typical, modern, rotary cement kiln consists of a cylindrical steel shell varying in length from 60 to 500 feet and in diameter from 5 to 12 feet (Fig. 101). These kilns are lined with high-temperature fire brick ranging in thickness from 6 to 9 inches, as very high

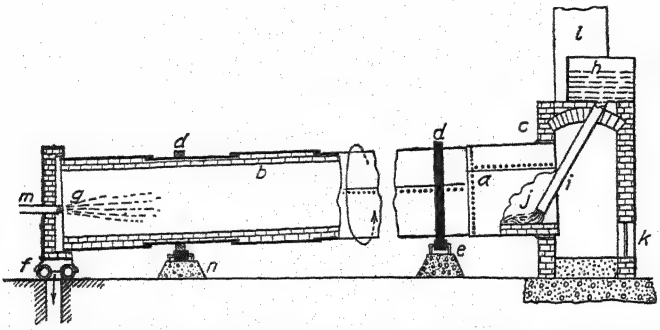

FIG. 101.—Rotary Portland cement kiln (wet process). *a*. Steel shell. *b*. Fire-brick lining. *c*. Air seal. *d*. Riding rings. *e*. Riding-ring rollers. *f*. Hood car. *g*. Flame. *h*. Slurry feed box. *i*. Slurry feed pipe. *j*. Slurry. *k*. Cleanout door. *l*. Stack. *m*. Fuel feed pipe. *n*. Base.

temperature is necessary to clinker the raw materials. This intense heat would destroy the unprotected metal shell of the kiln. One end is slightly elevated above the other to force the horizontal movement of the charge. The upper end is supplied with attachments for feeding and for conveying away the waste gases. The lower end is covered by a fire-brick lined, circular hood mounted on wheels and can be removed for repairing. Through this hood the fuel for firing is injected. The whole structure is mounted on roller bearings and is made to turn by a ring gear surrounding the outside which meshes with a pinion driven by a

motor. The fuel is generally powdered coal (although gas or oil can be used) which is blown in and causes a flame to shoot far up into the kiln. (The length of

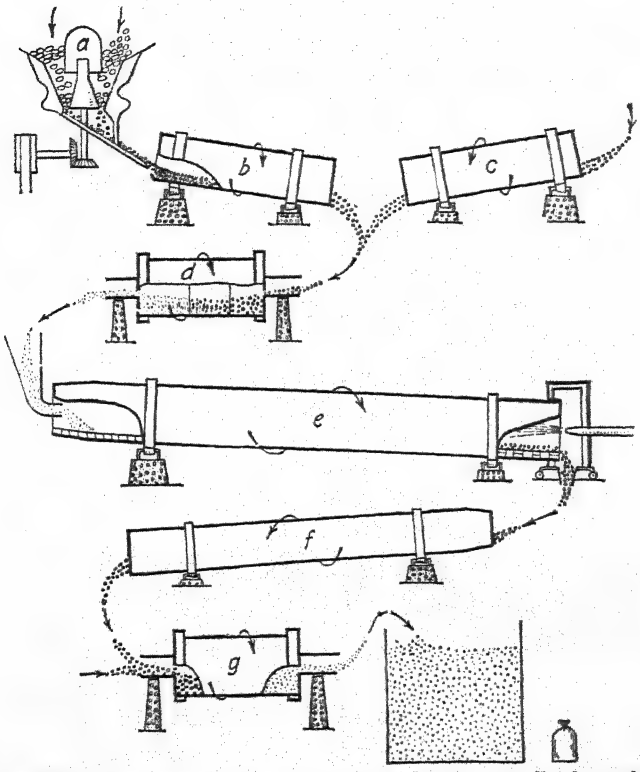

FIG. 102.—Flow sheet, Portland cement production. *a*. Rock crusher. *b*. Rock drier. *c*. Clay drier. *d*. Compeb mill. *e*. Rotary kiln. *f*. Rotary cooler. *g*. Compeb mill.

the burning zone is about 25 feet.) The raw mixture is fed in at the upper end and is slowly passed down to the lower end by the revolving motion of the kiln. (The rate is from thirty to forty revolutions per hour.) When it reaches the burning zone (about one-third

of the lower end of the kiln), it is fused and finally drops out as white-hot clinker about the size of marbles. The clinker is then cooled either in out-of-door heaps or in special rotary coolers and is ready for mixing with gypsum and final pulverizing. The heat from the coolers is often used to increase the temperature of the incoming air used for combustion. Some plants use waste-heat boilers for generating power to run the plant. A recent development in clinker cooling not only conserves the heat, but also renders the product easier to pulverize, and increases the quality of the cement. The finished cement is generally stored in large tanks from which it is drawn and filled into bags by machinery and is ready for shipment.

Wet Process.—In the wet process the raw materials are crushed and afterward pulverized (generally in compeb mills) in water producing a soupy slurry instead of a dry powder. This slurry is pumped to large correcting tanks, where it is thoroughly tested and properly proportioned before going to the kilns. From now on the process is practically the same as that for the dry process. The time required for burning in the wet process in a 250-foot kiln is about four and a half hours, or somewhat longer than that required for the dry process. The amount of fuel consumed is also larger. But this is largely compensated for by the facts that no preliminary drying is required before grinding, greater efficiency in grinding can be attained, and the raw mixture can be accurately proportioned with less trouble. The wet process is

gradually taking the place of the dry process, especially where new plants are being established.

Pozzuolan Cement.—A comparatively strong cement can be produced from a mixture of argillaceous material and hydrated lime. Formerly this cement was made of volcanic ash from Mount Vesuvius near the village of Pozzuoli in Italy, from which it takes its name. It was extensively used in the time of the

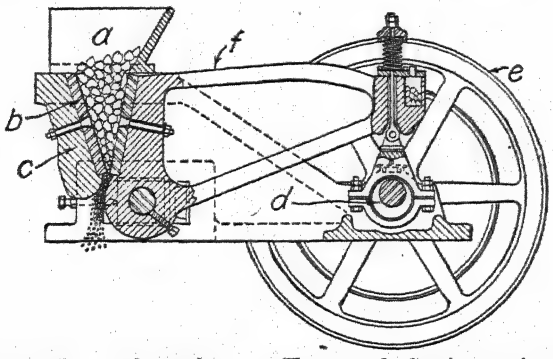

FIG. 103.—Jaw rock crusher. *a.* Hopper. *b.* Stationary jaw plate. *c.* Stationary jaw. *d.* Eccentric shaft. *e.* Flywheel. *f.* Swing jaw. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

Roman Empire, but in recent years there has been practically no demand for it.

Slag Cement.—In recent years considerable attention has been given to the manufacture of cement from blast-furnace slag. It has been discovered that by mixing and pulverizing together from 20 to 40 pounds of lime and 100 pounds of slag a very strong, durable cement can be obtained. Several plants have been equipped in different parts of the country for the manufacture of this cement. The industry becomes of more and more importance because of the excellent

quality of the product and the cheapness with which the raw-material slag—formerly a waste product—can be obtained.

Lumnite.—"Lumnite" is the trade name for a hydraulic structural cement manufactured from bauxite—the same kind of ore used in the production of metallic aluminum—and limestone fused in a temperature of about 3000°F. and afterwards cooled and pulverized. Its main features are resistance to corrosive action of acids and to high temperatures. It finds its principal uses in equipment for chemical plants, in mines, dairies, ice-cream plants, tanneries, rayon mills, and in other places where acids must be encountered, and for furnace cements and linings.

Unaflo Oil Well Cement.—"Unaflo Oil Well Cement" is the name given to a cement prepared more especially for sealing oil-well casings to keep out the water and other foreign materials after they have been sunk into the ground. Its special property is delay in setting, thus permitting it to be forced into all leaks throughout the casing before hardening. It is produced by adding a special retarding agent to regular cement instead of gypsum.

Another special cement that has come on the market in recent years is so-called "high early cement," because it hardens and acquires its full strength more quickly than ordinary Portland cement. For that reason it is valuable when speed of construction is of special importance. It is ground finer than ordinary cement and thus permits earlier chemical reaction in setting.

Concrete

Concrete can be considered an artificial stone produced by mixing together and hardening definite proportions of cement, aggregate (generally sand and stone), and water. Aggregates are divided into two general divisions: coarse and fine. Coarse aggregates are pieces from one-fourth to two and one-half inches across. Broken stone and pebbles are the most common forms. Fine aggregates are any materials that will pass through a one-fourth-inch mesh. Sand and fine stone screenings are the most common of the fine aggregates. Cinders and broken bricks can be used, but these materials are comparatively weak and should never be chosen when the concrete is to be exposed to the weather or where special strength is an important factor.

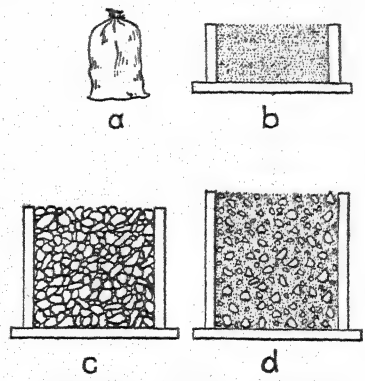

Fig. 104.—Typical concrete mixture. *a.* Bag of cement. *b.* One-half cubic foot sand. *c.* One cubic foot cracked stone. *d.* One and one-eighth cubic foot concrete. (*After Alpha Portland Cement Company.*)

All aggregates should be free from organic matter or other dirt, and if high-class work is required must be strong and compact. The amount of water used is important in determining the results. If either too much or too little is used, the quality of the concrete will be impaired. The proportioning of the

materials is also of special importance and is governed by the use for which the concrete is intended. Theoretically, there should be sand enough to fill the interstices between the coarser aggregate and cement enough to fill the interstices of the sand. The following are typical mixtures in common use:

Rich Mixture (1:2:3).—This means that one part of cement, two parts of sand, and three parts of stone or pebbles are taken. This mixture is used for road building, for waterproof structures, and for other purposes where great strength is required.

Standard Mixture (1:2:4).—This mixture is extensively used for reinforced work, for floors, roofs, columns, arches, tanks, sewers, etc.

Medium Mixture (1:2¼:5).—This mixture is used for foundation walls, abutments, piers, etc.

Lean Mixture (1:3:6).—This mixture is used for mass concrete work, as large foundations, backing for brickwork, etc.

Three grades of consistency are generally recognized: mush, quacky, and dry. Mushy consistency is thin and should be used only for thin walls, grout, etc. Quacky consistency is jelly-like and is the kind used for all ordinary mortar work. Dry consistency is only damp and is used when the work is to be tamped or packed in. Concrete building blocks are examples of its use. In mixing (especially when it is done by hand) it is better to mix thoroughly the cement and aggregate dry before adding the water. In this way a more uniform concrete can be obtained.

Plaster

Gypsum.—In recent years large quantities of gypsum plasters have appeared on the market. The most important of these are plaster of Paris, floor plasters, wall plasters, and Keen's cement. Plaster of Paris is produced by calcining finely pulverized, pure gypsum rock (calcium sulphate) in special kettles at a temperature ranging from 250 to 400°F. The kettles generally consist of upright, cylindrical, closed vessels supplied with furnaces for heating, and stirring attachments for agitating. Coal is used for fuel, and the time required for cooking is about an hour. During the process, water and other impurities are driven off, and chemical changes take place which leave a dense, dry powder which will harden when mixed with water. Floor plasters and hard finishes can be produced by calcining crushed impure gypsum rock (generally in upright kilns) for about three hours at a temperature of 850 to 900°F. The calcined material is then pulverized, generally in buhrstone or rock mills of the same type as were formerly used in grinding grain. Common wall-plaster materials can be made in rotary kilns similar in construction and operation to Portland cement kilns.

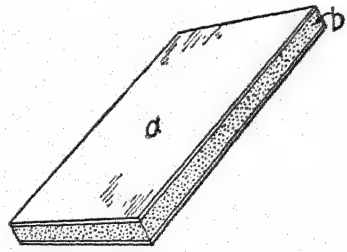

Fig. 105.—Wall board. *a*. Paper. *b*. Plaster.

A large percentage of the output of gypsum plaster is mixed with hair or other fibers to make "Adamant" and other brands of well-known patent wall plasters. It is also spread between two layers of paper to make wall boards, as in plaster board and sheet rock (Fig. 105). Keen's cement is produced in much the same manner as floor and finishing plaster, except that great care must be exercised in selecting pure gypsum rock and that the calcined product is treated with about 10 per cent alum before the final grinding. Keen's cement is a high grade of finishing plaster.

A large percentage of plaster of Paris is used for the manufacture of terra-cotta moulds, in images, ornamental plaster work, and white wall finish.

The principal gypsum rock deposits in the United States are in western New York, Virginia, Ohio, Oklahoma, Michigan, Kansas, Texas, and Iowa.

Lime, Cement, Concrete, and Plaster Terms

aggregate—Cracked stone, gravel, sand, or other material used to mix with cement in making concrete.

argillaceous material—Clay material.

ball mill—A steel cylindrical or conical revolving shell in which steel balls roll about and pulverize materials.

buhrstone mill—A grinding mill with two horizontal circular stones one revolving upon the other as in an old-fashioned grain mill.

calcining—Burning, as burning limestone to make lime.

calcium carbonate—Limestone especially suitable for making lime.

calcium sulphate—Gypsum rock from which plaster and plaster of Paris are made.

cement rock—Natural argillaceous limestone.

clinker—Chunks of material resulting from fusing together the raw Portland cement materials.

compeb mill—A closed, horizontal, rotating, steel cylinder containing compartments, each having different-sized balls for grinding and pulverizing raw cement materials.

dissociate—To break to pieces, to decompose, fall apart, etc.

dry process—The process of making Portland cement in which the raw materials are ground and burned dry.

gypsum—The name given to calcium sulphate rock, also a plaster made from the rock.

hydrated lime—Quicklime that has been pulverized and treated with water enough to make it fluffy.

hydraulic lime—Lime produced by calcining impure limestone.

incipient fusion—The beginnings of fusion.

intermittent kiln—A kiln in which the charge of raw materials is calcined and removed before another charge is introduced.

Keen's cement—The product obtained by calcining pure gypsum rock and adding 10 per cent alum before final grinding.

lime—A white calcium oxide, produced by calcining calcium carbonate.

limestone—A rock composed mostly of calcium carbonate. When it contains magnesium it is dolomite. (Crystalline limestone is marble.)

lumnite—A special cement highly resistant to acids and heat made from bauxite ore and limestone.

marl—A deposit of lime, sand, and clay in various proportions, usually in the bottom of ponds or marshes.

mixed-feed kilns—Upright lime kilns in which the fuel (coal) is mixed and burned with the limestone charge.

mortar—A mixture of sand and lime or cement used for covering walls or joining bricks or stones in walls.

natural cement—A cement made by calcining natural cement rock.

plaster of Paris—The product obtained by calcining finely pulverized pure gypsum rock at 400 to 600°F.

Portland cement—Hydraulic cement made by calcining and pulverizing a powdered mixture of limestone and clay and a small amount of gypsum.

quicklime—The immediate product obtained by calcining limestone.

Rosendale cement—A name given to natural cement because it was first discovered and made from rock found near Rosendale, N. Y.

slag cement—Cement made with blast-furnace slag as one of its ingredients.

slaking—Dissolving quicklime in water or air.

shale—Argillaceous, or claylike, rock, usually rather soft and laminated.

slurry—Ground raw cement materials in an amount of water to make a solution thin enough to run easily.

terrazzo—A kind of floor made of marble chips, sometimes in designs, and set in cement and polished.

tube mill—A revolving steel cylinder in which steel balls tumble against each other for pulverizing materials.

volcanic ash—Pulverized lava.

wet process—The process of making Portland cement in which the raw materials are ground in water.

Lime, Cement, Concrete, and Plaster Questions

Group I

1. What is the raw material for lime?
2. Describe an early lime kiln.
3. What is the chemical name for limestone?
4. When limestone is calcined (burned) what two main things are driven off?
5. What was the so-called "Plasterer's Company" of London?
6. What happens to quicklime when water is added?
7. Why should care be exercised in storing quicklime?
8. What are the two general types of lime kilns?
9. What is meant by a "mixed-feed" lime kiln? What is the objection to this type of kiln?

10. Explain how hydrated lime is produced.

11. Explain how hydraulic lime is produced.

12. What evidence have we that cements were used in early times?

13. By whom, about what time, and under what conditions did the natural cement industry start in this country?

14. Explain what is meant by natural cement.

15. Where was the first important natural cement industry started in this country? What name was given to the cement? What influence did this name have on other natural cement projects?

16. Name two other places in New York State where natural cement industries were started. Why were they started there?

17. Why has the use of natural cement largely been discontinued?

18. By whom, in what year, and under what condition was Portland cement discovered? What gave it its name?

19. What are generally the raw materials for Portland cement?

20. Where, by whom, and in what year was Portland cement first produced in this country?

21. What were the first important projects in which Portland cement was utilized in this country?

22. Name the two common processes for producing Portland cement, and explain what each means.

23. How was Portland cement formerly made in this country? In what year was this method changed?

24. Give the approximate size of the modern larger Portland cement kiln.

25. Why is the hood of the kiln mounted on wheels?

26. What is the fuel generally used for producing Portland cement, and in what condition does it enter the kiln?

27. How is a large Portland cement kiln mounted, and how is it caused to turn?

28. How much time is required for burning in a 250-foot kiln in the wet process?

29. Why should blast-furnace slag be especially profitable for the production of Portland cement?

30. Where is the center of the Portland cement industry?

31. What is the general theory as to the proportions of cement, sand, and stone for good concrete?

32. Give three common mixtures for concrete.

33. Name the common materials used for aggregates in concrete.

34. In mixing concrete by hand what procedure is best to follow?

35. Name three grades of consistency for concrete mixing.

36. Name some of the most important plasters obtained from gypsum.

37. Explain how sheet rock is produced.

38. Where are the principal gypsum rock deposits in the United States?

39. How is plaster of Paris produced?

Group II

40. What are the conditions in this country that make the production of lime fairly easy in all parts?

41. Why are rotary cement kilns installed on a slant? What determines how much slant these kilns should have?

42. What would determine the rate of speed at which a Portland cement kiln should revolve?

43. What would determine the length and diameter of a rotary Portland cement kiln?

44. Why is fuel coal for cement making first pulverized before it is introduced into the kiln?

45. Mention enterprises that have greatly aided the development of the Portland cement industry in recent years.

46. In what two special ways did early canal construction aid the cement industry?

47. When water is poured on sand the water disappears without apparently increasing the bulk. Where does the water go?

48. What is meant by reinforced concrete?

49. Mention some of the qualities that good concrete must possess.

50. What is meant by the burning zone in a kiln?

51. What is meant by finishing plaster? How should this differ from other plasters?

52. Name places where a rapid-setting cement is especially valuable.

BRICKS AND TILES

Bricks are made by mixing, moulding, drying, and burning clays. Their manufacture is one of the most ancient of industries. In the fourth millennium before our era the Chaldeans practiced the art of working clay and moulding it into forms for buildings and other purposes. We have the Biblical account of the Israelite slaves making bricks without straw in ancient Egypt (straw was used to aid in binding the clay together). Herodotus, the Greek historian, speaks of wonderful brick temples which he saw in Babylon in the fifth century B. C.

Historical Sketch.—The early Romans brought the art of brick making to Europe from the Eastern nations and developed it to a high degree, as is seen in the ruins of the buildings which they constructed in Rome and elsewhere. The Moors also showed themselves masters of the art and left monuments of their skill in the Alhambra and other buildings in Spain, some of which are still standing. Bricks were frequently held by many ancient peoples to be of so much importance that kings gave them their stamp, and modern excavations often disclose inscriptions on their surfaces that are of special historical importance.

It is probable that the beginning of the brick industry in England was during the Roman occupation, and it first came to America with the early English settlers. As early as 1611 brick making was started in Virginia, not far from the settlement of Jamestown. Records show that bricks were made in Massachusetts as early as 1629.

Many early buildings in America were constructed of bricks brought over from England and Holland as ballast for ships. The stables at Mount Vernon and the William Penn house in Philadelphia are said to have been constructed of these bricks. So common and useful an article as bricks, however, could not long be imported from Europe, especially when such an abundance of good clays existed on all side with plenty of wood in the near-by forests for burning. Consequently as soon as permanent settlements were started, bricks were generally made in the vicinity for fireplaces and chimneys.

Clays.—Before discussing the actual production of bricks it is important to know something of the clays and other materials from which they are made. Clay is the product of decomposed rocks from which the bond, as lime, potash, or soda, has been dissolved away, leaving only the clay behind. Clays are widely distributed in nearly every country and vary in consistencies from soft, plastic material to hard, rocklike shale; in fact, shale is nothing more than solidified clay.

Natural clays and shales vary in composition in various parts of the country. Red-burning clays are the more

prevalent, but buff-burning and other clays are also widely used, partly on account of their color and partly because coloring materials can be added to them to produce a wide variety of effects. Different manufacturing processes produce different surface textures. And so the whole sweep of color, in smooth and rough textures, is available, from the pure, severe tones of pearl grays or creams, through buff, golden, and bronze tints to a descending scale of reds, down to purples, maroons, and even the gun-metal black.

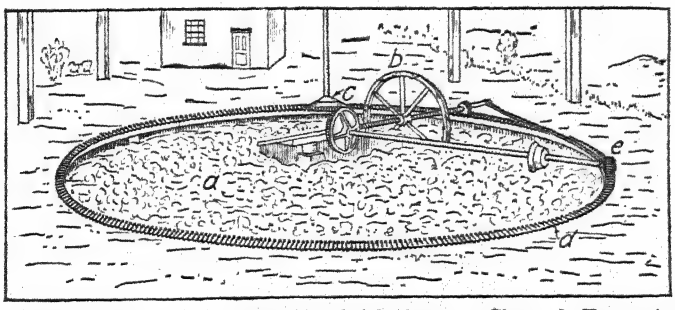

FIG. 106.—Ring pit for tempering brick clay. *a.* Clay. *b.* Tempering wheel. *c.* Driving gear. *d, e.* Rack and pinion. (*Courtesy of Chambers Brothers Company.*)

The most common kinds of clay are ball clay; china clay, or kaolin; fire clay; cement clay; and ordinary brick clay. Ball clay is fine and plastic and becomes white when burned. For this reason it is especially valuable for white earthenware. China clay is the finest of the clay family and is the variety used for high-grade chinaware, porcelain, etc. It is also used as a bond for artificial abrasives, as a filler for paper, in filters, and for many other special purposes. Fire clay is heat resisting, or refractory, and is used for furnace linings, crucibles, and other purposes where

high temperatures must be withstood. It is also used for fine glazed bricks and is often mixed with ordinary building-brick clays to produce certain color effects and other special characteristics. As a rule high-grade fire clays are found associated with coal measures. Cement clays contain lime and are used as one of the ingredients for Portland cement. As a rule they are found in shale form. Brick clays comprise a large variety of materials and are generally impure, being mixed with sand and other foreign matter; in fact, almost any kind of clay can be made into bricks.

Processes of Forming Bricks.—There are three general processes in use in the manufacture of bricks: the soft-mud process, the stiff-mud process, and the dry-press process. The equipment required for each depends upon the nature of the raw materials, the requirements of the finished products, and the different ideas of individual manufacturers. If shale is used, it must be pulverized, which is accomplished in a dry or wet pan grinder (Fig. 108).

In the soft-mud process the clay was formerly tempered (mixed) in a ring pit or, in recent years, by a pugging machine. The ring pit consists of a circular cavity in the ground from 2 to 4 feet deep and from 25 to 40 feet in diameter into which the raw clay is thrown (Fig. 106). The tempering is done by a wheel mounted on a horizontal arm, or shaft, with one end attached to a pivot located in the center of the pit. The mechanism is so arranged that the wheel travels sidewise as it revolves, similarly to the nut on a bolt.

The arm moves around on the central pivot like the hand of a clock and causes the wheel to revolve in the clay and describe a spiral curve, resembling the hairspring of a watch. A gear track, or some other mechanism, is generally constructed around the circumference of the pit to permit the power to be applied to the outer end of the arm and thus relieve the central mechanism of the enormous strain that would be necessary to force the wheel through the heavy mud from that point.

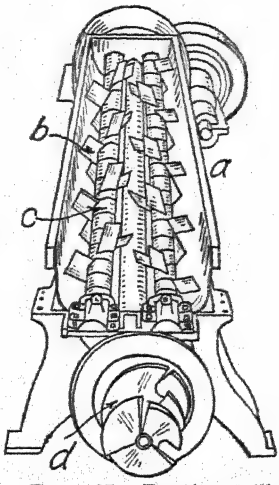

FIG. 107.—Pugging mill. *a.* Trough. *b.* Blades. *c.* Shaft. *d.* Discharging mechanism. (*Courtesy of Mueller Machine Company.*)

When the wheel reaches the central part, or the circumference of the pit, the motion is reversed, and the spiral is traced in the opposite direction. The process is slow and primitive and is rarely used. The pugging machine consists of a steel shell, or trough, equipped with a central shaft around which are attached heavy steel knives in the form of a spiral (Fig. 107). At one end is a hopper for receiving the clay, and at the other an opening for discharging. As the raw clay is fed into the hopper, it is caught by the knives and thoroughly mixed and forced out through the discharging end. The process is much quicker and cheaper than the ring-pit process and is generally used except when special ring-pit tempering is required. A process

of de-airing clay with a vacuum has recently been developed. It is claimed that clays so treated before moulding are stronger, more plastic, and more workable, and that when burned they present a cleaner cut and stronger product.

After tempering, the clay is ready to be moulded into bricks. In some instances, this is done by hand in wooden moulds, but the process is slow and expen-

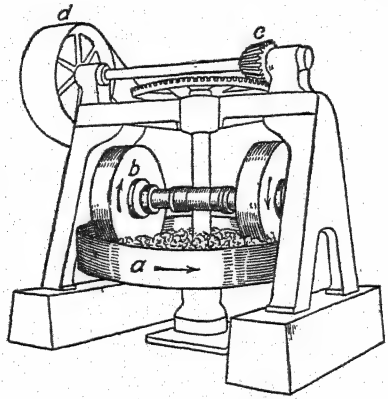

FIG. 108.—Dry or wet pan grinder. *a*. Pan. *b*. Grinding wheels with steel tires. *c*. Gear. *d*. Pulley. (*Courtesy of International Clay Machinery Company.*)

sive and is used only in a few small yards or when special features are required in the finished product. There are two general types of brick-moulding machines: the plunger type and the screw or auger type. The plunger type consists of a steel shell equipped with a rigid plunger which forces the plastic clay into moulds (Fig. 110). From four to eight bricks are produced at one operation. As soon as the pressure is removed from one lot, another set of moulds is adjusted in place to receive the next batch; thus the

process is made continuous. Bricks formed by being pressed into moulds have sharper corners and smoother surfaces than those made in the auger machine and are better suited for face and other high-grade work.

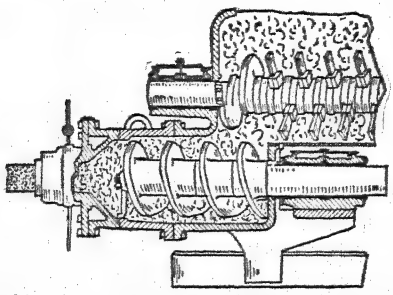

FIG. 109.—Combination pugging machine and auger brick machine. (*Courtesy of International Clay Machinery Company.*)

The auger machine is used with the stiff-mud process. This machine consists of a cylindrical steel shell equipped with an interior central screw or auger. At one end is a hopper for receiving the clay, and at the other end a die for reducing it to a column of the proper form and size (Fig. 111). The action of the

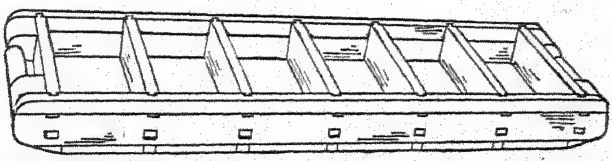

FIG. 110.—Brick moulds. (*Courtesy of Lincoln Iron Works.*)

machine is very much the same as the ordinary, rotary kitchen meat grinder or an auger bit forcing out shavings when boring wood. The tempered clay is fed into the hopper and is forced by the revolving auger through the die in a long column or stream

similar to tooth paste squeezed from a tube. A conveying belt carries it to a cutting table to be sliced into bricks. There are several types of automatic cutting tables on the market. One of the most common of these is known as the "automatic side cutting machine." This machine consists, in the main, of a table upon which is mounted a reel composed of two rings or wheels about three feet in

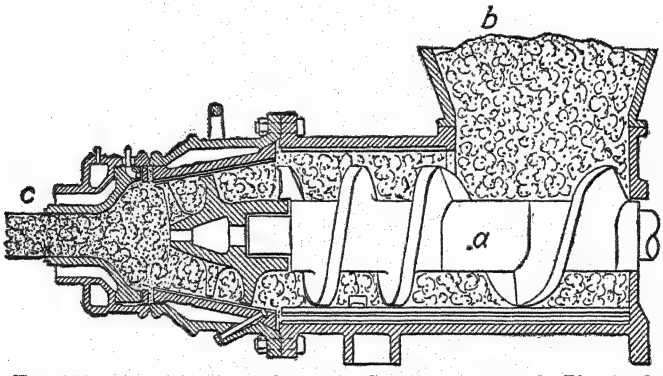

FIG. 111.—Auger brick machine. *a*. Screw or auger. *b*. Plastic clay *c*. Die for shaping clay column for bricks. (*Courtesy of Chambers Brothers Company.*)

diameter and about the same distance apart, revolving on the same center (Fig. 112). Two or three sets of wires are adjusted between the wheels equidistant apart and radially from the center of the reel. In a way, the wires act as spokes for the reel. The distance between the individual wires is the same as the size of the bricks. The column of clay passes through the reel parallel to its axis and the descending wires cut off the bricks as it passes along. The number of wires in each set (and hence the number of

bricks cut at one stroke) is from twelve to twenty-four depending upon the size of the plant and the capacity of the brick machine with which it is operating. The conveyor that carries the bricks away from the machine operates about twice as fast as the one that brings the column up, with the result that the bricks are separated as soon as they leave the table and can easily be picked up by the workmen.

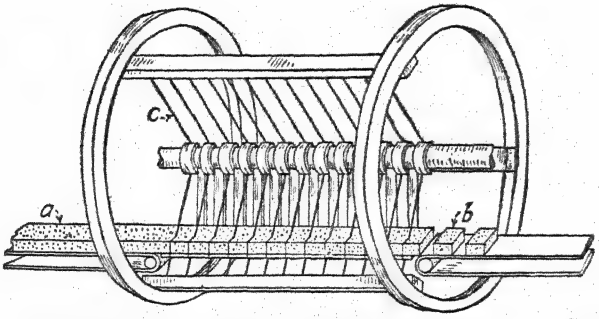

FIG. 112.—Side wire automatic brick-cutting machine. *a*. Clay. *b*. Bricks. *c*. Wires.

Another type of wire brick-cutting machine is known as the "rotary side cutter." This machine consists of a table at the end of which is attached a large wheel that revolves at right angles to the moving stream of clay (Fig. 113). The wheel is constructed with from two to eight piano-wire spokes. As the column of clay moves along through the wheel, the spokes descend and slice off the bricks, each spoke cutting off one brick. When bricks of a different thickness are required, the speed of the wheel relative to that of the moving column can be adjusted to produce the desired results.

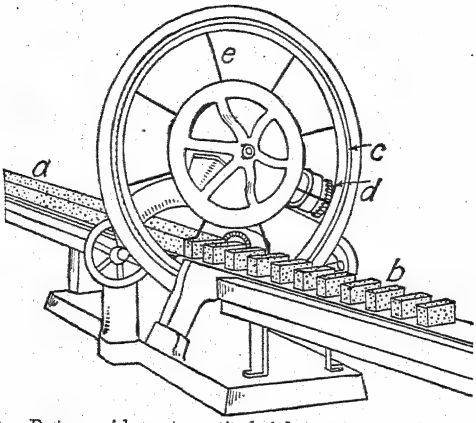

FIG. 113.—Rotary side automatic brick-cutting machine. *a.* Column of clay. *b.* Bricks. *c.* Rim. *d.* Gear. *e.* Wire. (*Courtesy of Chambers Brothers Company.*)

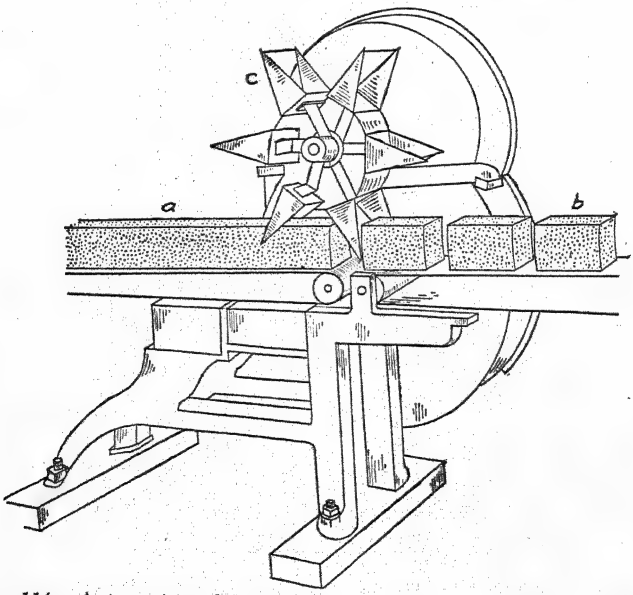

FIG. 114.—Automatic end brick-cutting machine. *a.* Column of clay. *b.* Bricks. *c.* Wire reel. (*Courtesy of Chambers Brothers Company.*)

A third type of wire brick-cutting machine is known as the "end cutter" because the bricks are cut endwise instead of sidewise. This machine consists of a table upon which is mounted a double five- or six-pointed revolving reel (Fig. 114). The corresponding points of the wheel are about three inches apart and are connected with piano wires parallel to the axis. The distance between any two adjacent points is the same as the length of one brick. As the clay column passes through underneath the revolving reel, the wires descend and cut off the bricks, each wire cutting one brick. Bricks cut by this machine are slightly curved in their ends and can easily be distinguished from those cut by the side cutting machines. Wire-cut bricks can always be identified by the rough wire marks left on their surfaces. Machines are now in use for handling and setting the bricks both in the drying rooms and in the kilns.

Drying.—After being formed, bricks must be thoroughly dried before being burned to prevent them from distorting and breaking up from their own weight in the kilns. In small plants, and in some larger plants where climatic conditions are favorable, open-air drying is practiced; but as a rule in the larger plants, especially where the output is continuous, artificial drying is used. There are two general types of artificial driers, namely, the tunnel drier and the room drier. The tunnel drier is a long, narrow chamber operated on much the same principle as the progressive kiln for seasoning lumber. Heat is supplied either directly or by waste heat from the

kilns. The cars of bricks enter the receiving end of the tunnels and are gradually passed along until they are removed dry from the discharging end.

The time required for drying is from three to five days depending upon the nature of the bricks and the conditions of the weather. Room driers are generally single rooms equipped with tracks and other facilities for handling the bricks quickly. They are generally constructed with flues underneath the floors through which waste heat from the kilns passes for drying. The time required for drying in this type of drier is about the same as that for tunnel driers. In the largest plants these drying rooms often have a capacity of 1,000,000 bricks; and in some plants several room driers in operation.

Burning.—Among the most important divisions of brick making is firing or burning. This is done in kilns, of which there are three general types: the temporary (although temporary kilns are becoming obsolete), the semi-permanent, and the permanent. The permanent type can be again classified as circular, rectangular, up draught, down draught, intermittent, and continuous. The temporary type is simply a stack of dried bricks piled with open spaces to allow for the circulation of heat and with arched openings at the bottom for furnaces (Fig. 115). When the stack is completed, it is plastered over with mud to retain the heat. The fuel can be wood, coal, or gas, and the time required for burning is from seven to ten days. Bricks nearest the fires are burned hard (often vitrified), while those farthest away are often

soft and salmon colored and of an inferior quality. After burning, the bricks are allowed to cool in the kilns for a few days, when the kilns are torn down and the bricks are removed to make room for the next batch.

Semi-permanent kilns are rectangular in form and generally have two permanent side walls with furnaces constructed at their bases. Flues underneath the floor connect with the furnaces and distribute the

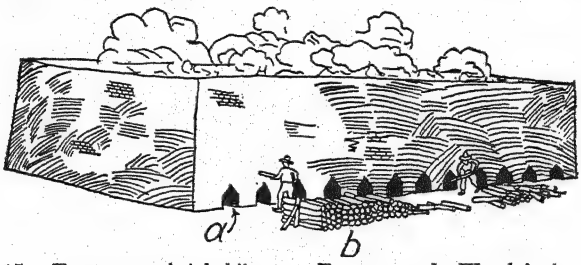

FIG. 115.—Temporary brick kiln. *a*. Furnaces. *b*. Wood fuel. (*Courtesy of International Clay Machinery Company.*)

heat evenly to the interior. When the kilns are charged, the space between the walls is filled with bricks, and the top and ends are plastered over with mud, except where vent holes are left in the top for the escape of waste gases. The fires are started, and the burning proceeds in much the same manner as in temporary kilns. The fuel used can be either coal or gas. Both the temporary and the semi-permanent kilns are of the up-draught type. Sometimes larger semi-permanent kilns have capacities of 1,000,000 bricks or more to a batch.

Permanent kilns can be either circular or rectangular in form. They are also either down draught or up

draught. A typical circular down-draught kiln consists of a reinforced, fire-brick lined, circular structure with a dome-shaped roof (Fig. 116). A door is at one side, and a number of furnaces are constructed in the outer wall. The number varies from eight to twenty according to the size of the kiln and the character of the ware to be burned. Brick baffle walls are located in the interior opposite the furnaces,

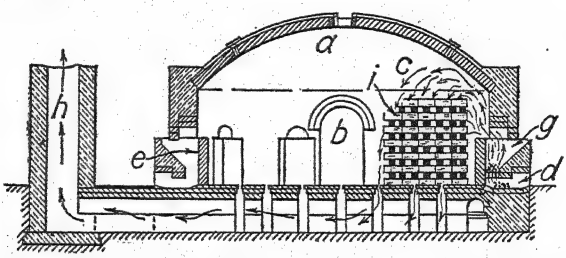

FIG. 116.—Circular down-draught brick kiln. *a.* Arched roof. *b.* Door. *c.* Flames. *d.* Ash pit. *e.* Baffle wall. *g.* Furnace. *h.* Stack. *i.* Bricks. (*Courtesy of International Clay Machinery Company.*)

to direct the heat to the arched roof from which it is deflected downward evenly through the bricks. By this system practically all of the bricks receive the same amount of burning. Numerous openings in the floor connect with flues underneath which convey the waste gases to the stack or to the drying rooms. The larger down-draught circular kilns are about 35 feet in diameter and have a capacity of about 30,000 bricks per batch. The average time required for burning is about seven days, and seven days more are allowed for cooling.

Rectangular down-draught kilns do not differ materially from the circular down-draught type, except that they are rectangular in form instead of

round (Fig. 117). In recent years compartment, or continuous, kilns have been developed which practically do away with extra drying equipment. These kilns generally consist of a series of chambers arranged so that the waste heat from one chamber can be carried over into the next, and so on through the whole series. By using this system practically all of the heat can be extracted from the waste gases before they reach the stack. The "Hoffman ring kiln" is a

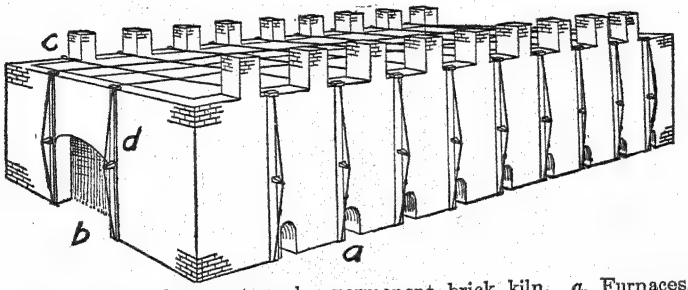

FIG. 117.—Modern rectangular permanent brick kiln. *a*. Furnaces. *b*. Door. *c*. Chimneys. *d*. Reinforcing brace. (*Courtesy of International Clay Machinery Company.*)

good illustration of this type. In the larger plants several types of kilns may be seen in operation at the same time, the type chosen depending upon the character of the bricks being burned and the ideas of the individual operators. The temperature required for burning is practically the same for all types of kilns and varies from about 2000°F. for common red bricks to 3500°F. or over for silica and magnesite refractory bricks.

Glazed Bricks.—All ordinary bricks are ready for the market as soon as they are burned and cooled. But in certain instances they are glazed, either to give

them artistic appearance or to make them impervious to water and the attack of acids. There are three general methods of glazing: natural glazing, common-salt glazing, and glazing by the application of special

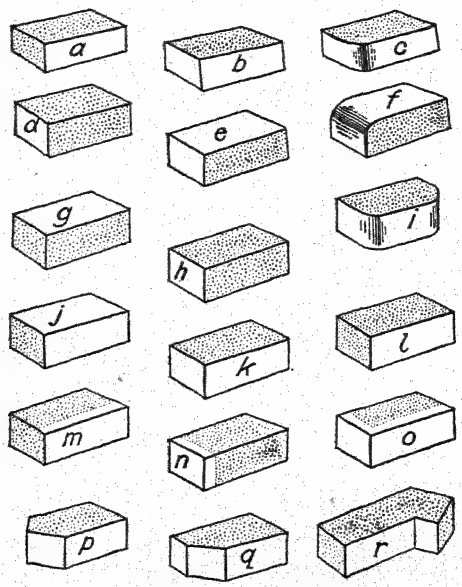

FIG. 118.—Types of enameled bricks. *a.* Stretcher. *b.* Quoin. *c.* Bullnose. *d.* Header. *e.* Flat quoin. *f.* Flat bullnose. *g.* Flat stretcher. *h.* Double header. *i.* Double bullnose. *j.* Stretcher on flat. *k.* Double quoin. *l.* Double stretcher. *m.* Lipped stretcher. *n.* Lipped header. *o.* Lipped quoin. *p.* Exterior octagon. *q.* Octagon chamfer. *r.* Interior octagon. (*Courtesy of American Enameled Brick and Tile Company.*)

solutions and second firing. In natural glazing the clay itself slightly fuses on the surface and causes a natural glaze. This occurs only when the bricks are fired at a very high temperature. In common-salt glazing, common salt is thrown on the fire during the burning process. The vapors rise and settle on

the bricks and cause a chemical reaction that leaves a fused, glassy surface.

When colors or other high-class glazes are required, the surfaces of the bricks are treated with clay washes or slips containing compounds that fuse and produce the desired effects, when a second firing is administered. By using different compounds a large variety of most pleasing colors and effects can be secured. Glazed bricks are expensive and are generally used only for special high-class work. Generally, when artistic glazed-brick effects are desired, it is customary first to construct the wall of ordinary bricks or concrete and then finish on the surface with thin wall tiles of the proper size. The tiling finishes of subway stations and the Holland Vehicular Tunnel under the Hudson River are striking examples of this practice.

Some Kinds of Bricks.—There are many varieties and styles of bricks on the market (Fig. 118). The following are a few of the more common standard kinds: common red bricks, face bricks, glazed bricks, paving bricks, fire bricks, sand-lime bricks, engineering bricks, Roman bricks, and Norman bricks.

Common red bricks are the most abundant and are produced by burning ordinary clays containing oxide of iron.

Face bricks are of many varieties, styles, and colors. As a rule a larger part of the pressed bricks are used for facing. Face bricks often have rough, artistic surfaces and are designated as "tapestry" bricks or by some other suggestive trade name. Sometimes

granulated slag, manganese ore, or other materials are mixed with the clays and produce a mottled effect. Face bricks are also produced in a large variety of colors and shades.

Paving bricks are made of special clay. As a rule, they are larger than common bricks and have their corners rounded. They are burned very hard to withstand severe wear.

Sand-lime bricks are made of a mixture of sand and lime. They are formed by pressing the mixture into moulds with very heavy pressure and afterward hardened in a closed cylinder under about 125 pounds of steam pressure.

Fire bricks are produced from special refractory clays or other refractory materials. Their principal use is for furnace linings and in other places where high temperatures must be withstood. They are made in a variety of shapes and sizes so as to work to the best advantage in arches and other special forms of furnace linings. A good example of the use of fire bricks in special forms is the checkerwork of blast-furnace stoves (Figs. 139 and 182). As a rule, fire bricks are classified as engineering bricks.

Roman and Norman bricks are made larger generally for architectural effect and are used for face work. Some manufacturers are beginning to make special bricks of larger size but with cavities, or hollows, in them. This reduces the weight, saves materials, and lessens the cost of laying. Examples of such bricks are the so-called "balloon bricks" and the "jumbo bricks," recently put on the market. The

balloon brick is about 16 per cent larger than the standard brick, but it is perforated with cavities so that its weight is practically the same. The jumbo brick is a hollow block 3½ by 8 by 12 inches and takes the place in a wall of four and two-thirds standard bricks. Both of these products have been carefully tested out and are in considerable demand for building purposes.

Common Sizes of Bricks.—The following are standard sizes of ordinary building bricks adopted by the National Brick Manufacturers Association:

	Inches		
Common red bricks	2¼ by	3¾ by	8
Face bricks	2¼ by	3¾ by	8
Paving bricks	3 by	4 by	8½
Roman bricks	1½ by	4 by	12
Norman bricks	2⅜ by	4 by	12

Wall and Floor Tile.—There are many kinds and styles of wall and floor tiles on the market, each involving certain modifications in its respective process of manufacture. The following is typical of the processes used in the production of high-grade, bright, glazed wall tile:

In the first place, the selection and compounding of the raw materials are of special importance. Slight variations in the proportions of the materials used might seriously affect the quality of the finished product. As a rule, clays suitable for high-grade tile are found in widely separated districts and often must be transported considerable distances to reach the factories. As an illustration of this, one large

firm obtains ball clay from Kentucky, kaolin from Florida, feldspar from Maine and Canada, china clay from Cornwall, stone from England, flint from Pennsylvania, and sagger stone from New Jersey.

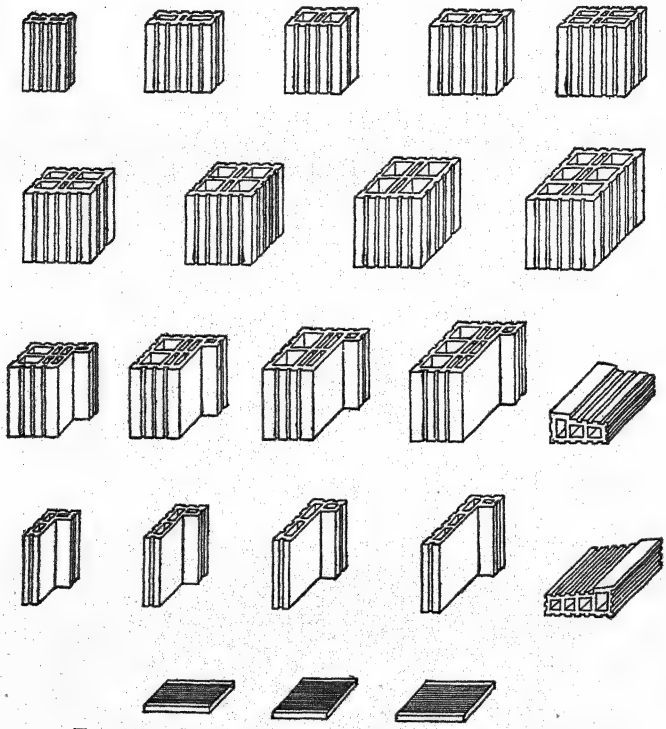

FIG. 119.—Standard wall and jamb tile. (*After Pulver.*)

The clays are first weighed and mixed according to definite formulas. The mixture is then washed, screened, passed under electric magnets to remove the iron, filtered, and dried. It is next crushed and treated with enough water (about 12 per cent) to make it plastic, after which it is pressed into moulds

of desired forms. The pieces are then slowly dried in special drying rooms to prevent warping and cracking. It is now ready for firing, which does not differ essentially from firing bricks and other ordinary clay products, except that the kilns must be of suitable design and size to meet the special requirements. As wall tile is generally made in small pieces, saggers are used for convenience in handling them in the kilns. The time required for firing is about ninety-six hours. After the kilns are cooled, the tile (now known as "bisque tile") is removed and is ready for the glazing process.

Glazing is one of the most important branches of the industry. As with bricks and other glazed clay products, colors and other artistic effects are secured by treating the ware with solutions of metallic oxides and afterward subjecting it to a second firing which fuses and leaves the desired colors by chemical reaction. Among the most common elements used for coloring are iron oxide for red, cobalt for blue, and chromic oxide for green. The number and variety of designs and tints possible to produce are practically limitless.

Floor Tiles.—Up to the point of firing, the processes involved in the production of floor tiles do not differ materially from those used for wall tile. Floor tile is a single-fired product and is vitrified instead of being glazed; that is, it is fired at a temperature sufficiently high to leave the ware hard and compact and unable to absorb moisture, while wall tile must be more or less porous to hold the glazing solution

properly. As soon as the firing process is finished, the smaller sizes of floor tiles are ready to be pasted on cloth (in designs if desired) and packed for shipment.

Brick and Tile Terms

art tile—Fancy tiles for walls, fireplaces, etc.

auger machine—A hollow, cylinder-like machine in which a spiral or auger-like part revolves, mixing the clay and forcing it through a die at the end.

automatic cutting table—A table upon which a column of clay travels and is cut automatically into bricks by descending wires.

baffle wall—A wall in a kiln against which direct heat strikes and is deflected to other parts of the kiln.

balloon bricks—Bricks about 16 per cent larger than standard bricks but perforated to reduce their weight.

bisque tile—Unglazed tile.

brickbat—A piece, usually half, of a brick.

cement bricks—Bricks made from a mixture of Portland cement and sand or cinders.

chimney tile—Special tile for chimney flues, around which bricks or other masonry are laid.

continuous kiln—A compartment brick kiln in which the waste heat from one compartment is utilized in the next.

down-draught kiln—A brick kiln in which the heat passes downward through the brick to holes in the floor and on to the stack.

drain tile—Special hollow tile for draining wet places, also sewer tile.

dry pan—A large revolving, horizontal, steel pan in which heavy steel disks run for pulverizing clay.

enamel bricks—Fine quality of glazed bricks.

face bricks—Better grades for bricks used for fronts of walls.

fire brick—Bricks made from a very refractory clay to withstand intense heat.

fire clay—A highly refractory (heat-resisting) clay of magnesia or silica composition.

flint clay—Brick clay produced by grinding flint rock.

glazed bricks—Bricks coated with a glossy surface made by fusing on a glazing material.

grinding pan—Same as dry pan.

hand method—Moulding bricks by hand.

iron oxide—Impurity in iron that causes the red color in bricks (iron rust).

jumbo bricks—Hollow clay blocks, 3½ by 8 by 12 inches, equal to about four and two-thirds standard bricks in a wall.

magnesite bricks—Refractory bricks made from magnesia.

pallet—A small board upon which green bricks are placed for handling.

pug mill—A mill with spiral knives revolving inside for mixing clay.

saggers—Refractory containers used for holding smaller articles when firing.

shale—Argillaceous rock, fossil rock.

silica bricks—Refractory bricks made of silica.

soft bricks—Bricks only partly burned.

soft-mud machine—A brick machine for making brick out of soft or wet clay.

stiff-mud machine—A brick machine for making bricks out of very stiff clay.

tunnel driers—Driers for bricks, constructed in the form of tunnels supplied with artificial heat.

up-draught kiln—A brick kiln in which the heat passes upward through the bricks from furnaces below.

wet pan—Same as dry pan, except that the clay is ground wet, and the pan must be water-tight.

Brick and Tile Questions

Group I

1. What famous historian mentions seeing bricks in the temples of ancient Babylon?

2. Where and about what time did brick making start in this country?

3. Name two historic buildings in this country constructed of bricks brought from England.

4. Name some of the most common kinds of clay.

5. How do clays originate?

6. Name the three general processes of manufacturing bricks, and explain the meaning of each process.

7. How could you distinguish wire-cut bricks from pressed bricks?

8. What is meant by standard bricks? Name some of the sizes.

9. Explain why bricks must be thoroughly dried before being loaded into the kilns.

10. Explain the ring pit and tell how it operates.

11. Explain how bricks are separated on the conveying belt as they leave the wire-cutting machine.

12. Name and explain the three general types of brick kilns.

13. What are the two sources of heat for brick driers? Explain which should be more economical.

14. How much time is required for burning bricks in an ordinary kiln?

15. What are the sizes and capacities of some of the larger down-draught brick kilns?

16. About what range of temperature is required for brick burning?

17. Name and explain briefly three methods of glazing bricks.

18. How are various colors in glazed brick secured?

19. Name some of the more common kinds of standard bricks.

20. What element gives brick their red color?

Group II

21. Why were bricks among the first commodities to be made by the early settlers?

22. How did using bricks for ballast cheapen their cost in this country?

23. How do bricks aid in learning history?

24. What are the general conditions that make brick making possible in nearly all parts of the country?

25. A column of clay travels 48 feet per minute; how fast must an eight-spoke wire-cutting wheel revolve to cut the bricks 2 inches thick?

26. From what part of the kiln are the bricks apt to be the hardest?

27. Give two reasons why a continuous kiln should be more economical than the single-compartment type.

28. Give the main reason why several small furnaces are used in brick kilns instead of one large furnace.

29. Mention advantages and disadvantages in the use of artificial drying, and in the use of natural drying.

30. Why is wall tile used more extensively for face walls than glazed brick (for example, New York subway stations and the Holland tunnel)?

31. Mention factors that would determine the use of open-air drying.

32. What particular advantage is the use of saggers in firing small tile?

33. What would determine the length of time required for open-air drying?

34. Give two reasons why white tile is especially desirable for the lining of the Hudson river vehicular tunnels.

35. Why are ordinary railroad tunnels not lined with white tile?

36. Explain why wall tile is especially good for bathrooms.

TERRA COTTA AND SANITARY WARE

Historical Sketch.—Terra cotta, as the name implies, is burned earth or clay. Because of its strength, durability, and the ease with which it can be moulded into forms, it is one of the important building materials. Like bricks its use dates back to very remote antiquity. Relics of terra-cotta ware have been found in the ruins of a large number of ancient

cities. It entered not only into the construction of the palaces of kings but also into that of the abodes of the common people. It was used for tombs, coffins, paving, public buildings, sewers, water pipes, and many other purposes. From the designs of terra-cotta relics and the inscriptions they often bear, we obtain some of our most authentic records of history and knowledge of ancient art.

Raw Materials.—The essentials of the manufacture of terra cotta have not changed through all the ages. More scientific knowledge of clays and the introduction of modern machinery in its manufacture, however, have made possible its production on a much larger scale and at a lower price. As a rule, the clays used are of the alumina-silicate variety and are higher grade than those used for ordinary bricks. They must be free from organic matter, coarse sand, or other foreign materials that would impair strength or discolor the surface of the ware, when fired. Several clays are mixed together, and to the mixture is added about one-fourth in bulk of clean sand or pulverized grog (old ground-up saggers or old terra cotta) to give strength and rigidity and to assist in holding the material together during the firing.

Designing and Moulding.—In a typical process the clays are crushed, pulverized, and pugged in practically the same manner as in the manufacture of high-class brick clays. The mass is then covered with wet cloths and allowed to stand for a few days to cool and temper. Certain chemical changes take place during the cooling process that render the clay

stronger and easier to mould. If the pieces are to be of standard design, stock models and moulds can be used for their production; but if they are special, templates, or patterns, are worked out in the draughting room from the architect's plans. Because clay

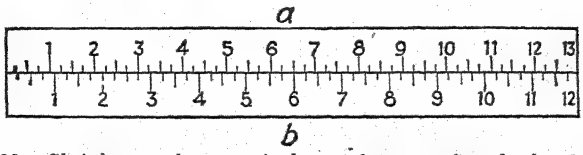

FIG. 120.—Shrinkage ruler, one inch per foot. *a.* Standard ruler. *b.* Shrinkage ruler.

shrinks about one inch to the foot in drying, all templates must be that much larger than their finished products. As a rule, this difference is taken care of by using a shrinkage ruler (Fig. 120). (The same principle is employed in pattern making for metal castings.) If only straight and easy lines are involved

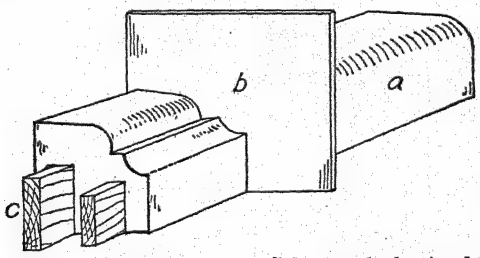

FIG. 121.—Moulding terra cotta. *a.* Column of plastic clay. *b.* Zinc template. *c.* Pieces of wood for reinforcing.

in the designs, the moulding can be done with zinc templates or by extruding the clay through a die (see Fig. 111); but if they involve delicate and artistic curves, they must be worked out by hand, often by highly skilled workmen. Often the production of a

single piece requires the work of an artist for several days or even weeks.

When templates are used, lumps of plastic clay are placed on a modeling table, and the templates worked back and forth through them until the desired contour is produced (Fig. 121). As a rule, straight strips of wood are embedded in the lumps of clay to aid in holding them in shape while being moulded and to leave the pieces hollow after they are removed. The extruding process is the same as that used in the auger brick machine except that the die has the form desired for the terra cotta. Extruding has rapidly replaced template moulding. When duplicate pieces of larger, irregular ware are required, they are made in special moulds. At first, models of the exact pieces are made of clay or plaster of Paris. From these models moulds are secured by embedding or packing them in plaster-of-Paris mortar. After the moulds harden, the models are removed, leaving the cavities in which the terra-cotta pieces can be formed. The process is somewhat similar to making moulds in sand for castings in a foundry. Because of the many undercuts often found in the designs of terra cotta, the moulds must frequently be made in sections so that they can be removed without damage to their parts. When once a good mould is secured, however, it can be used for a large number of duplicate pieces.

Before the moulds are filled, they are coated over with a wash and sometimes sprinkled with fine sand to prevent the clay from sticking to them. The filling is sometimes done by hand as no machine has yet

been invented that will perform this part of the work satisfactorily for certain kinds of ware. In common practice the moulder throws lumps of soft clay into the moulds with considerable force, the impact forcing the plaster material into all crevices and corners. A common modern practice is to blow the slip (thin clay) into the moulds with air pressure. As soon as the pieces have dried sufficiently to permit of handling without breaking, the moulds are removed, and the ware is dried and made ready for firing. Drying is generally accomplished in a drying room and must be done slowly and with care to prevent warping and cracking.

Glazing.—If the ware is to be glazed, otherwise than with natural or salt glazing, the glazing materials are applied before the firing process. Probably no other branch of the industry requires more care and scientific management than this. It is here that the services of the trained industrial chemist are necessary. Any kind of glazing material will give a smooth, glossy surface, but the many delicate colors and designs often seen in terra-cotta construction require a knowledge of materials and compounding that only the expert can supply. Glazing materials are generally mixed with a clay wash and applied with a brush or by dipping or spraying if the color is to be uniform and the ware coated on all sides.

Firing.—Common types of kilns used for burning terra cotta are very similar to circular, down-draught kilns for firing bricks, except that they are generally smaller, the typical size being about 16 feet in diam-

eter and 8 or 10 feet high. In some types the stack is in the center, and in others it is at one side. In either case the heat is furnished by furnaces in the side walls and passes through the ware to the roof from which it is deflected to openings in the floor to flues that lead to the stack. The pieces must be placed in such positions that the air and heat can circulate freely on all sides. In charging, also, care must be exercised to distribute the load so that the bottom courses will not be damaged by the weight of those above. The fuel can be gas, coal, or oil, and the temperature required ranges from 2000 to 2200°F. The time required for firing an ordinary batch is about 100 hours, after which the kilns and their contents are allowed to cool for five days, when the ware is removed, checked up, and is ready for shipment.

In case of designs for special construction, as archways, mantels, etc., checking up is generally done by placing the pieces, by superposition, on layouts, or patterns, of the actual construction that the terra cotta is to occupy in the building, drawn full size on a floor or table. Each piece is carefully numbered to indicate where it goes, so that there can be no confusion as to its proper place. A slight mistake in this part of the work may result in serious delay and heavy expense.

Sanitary Ware.—So-called "sanitary ware" (clay tubs, bathroom fixtures, sinks, and the like) is produced in much the same manner as terra cotta. High grade clays are required if satisfactory results are to be obtained. The larger percentage of the ware is

formed by casting the clay slip in molds with air pressure. Special forms are ordinarily built up by hand. Because of the large sizes and hollow nature of the articles, special skill is required to prevent damage in handling. Formerly all sanitary ware was glazed white, but recently colors have been developed.

Terra-cotta Terms

built-up work—Terra-cotta articles formed of plastic clay in pieces or sections, generally by hand.

grog—Broken pieces of old terra cotta or sagger ground up for mixing with new clay for new ware.

matrix (mould)—A specially designed cavity, usually of plaster, in which terra-cotta plastic clay is packed to produce forms.

sanitary ware—Wash tubs, sinks, tanks, and ordinary bathroom equipment formed of clay, baked and glazed.

shrinkage ruler—A special ruler for measuring, with the divisions proportionately larger than the standard ruler, to offset the shrinking of terra-cotta ware during the process of drying and firing.

template—A form usually cut from sheet metal with which to mould or work out straight terra-cotta forms (mouldings).

undercut—A cavity or depression, generally in the side of a mould, made by a projection on a pattern or model. It prevents the model from being drawn in the usual way without damaging the mould.

Terra-cotta Questions

Group I

1. What does the term "terra cotta" mean?

2. How do clays for terra cotta differ from those for common bricks?

3. What evidence have we that terra-cotta production is an ancient art?

4. Why are terra-cotta clays allowed to stand for a time after being mixed before they are moulded into form?

5. Why are moulds for terra cotta sometimes made in sections?

6. How are the models made from which the moulds for terra-cotta pieces are formed?

7. What material is generally used for the moulds?

8. What is meant by a template? What process is taking the place of template moulding?

9. Why is a large part of terra-cotta moulding done by hand?

10. How long should terra-cotta pieces be allowed to stand in the moulds?

11. What particular care must be exercised in drying?

12. What is a shrinkage ruler? How is it graduated?

13. In what type of kiln is terra cotta generally burned?

14. How long a time is generally required for burning terra-cotta ware? How long is allowed for cooling?

15. How is the final test for accuracy of special terra-cotta construction done?

16. About what temperature is required for firing terra cotta?

Group II

17. Why are moulds generally used for forming irregular terra-cotta ware?

18. Why is zinc generally used for templates instead of sheet steel?

19. What are some of the elements that produce different colors in terra-cotta ware?

20. Why is terra-cotta ware sometimes made hollow?

21. What class of work is generally formed, or moulded, by hand instead of in moulds? What art does this resemble?

22. In what part of a country are terra-cotta plants likely to be located?

23. Give two reasons why terra-cotta ware is suitable for use in construction with building stones.

24. What is taking the place of terra cotta in certain kinds of building construction?

ABRASIVES

An abrasive is any substance which because of its hardness and sharpness will wear away or abrade other substances. The term as a rule, however, is confined to sharp, gritty materials used for sharpening, grinding, and polishing.

Kinds of Abrasives.—Two general kinds of abrasives are recognized: natural and manufactured. Natural abrasives are those found in the earth; and for sharpening and grinding purposes many of them need no further treatment than shaping to the desired form before being ready for use. Manufactured abrasives are generally produced by fusing together certain elements with intense heat (generally in an electric furnace) and afterward crushing the product into grits of the desired size. In addition to this there has recently come on to the market a crushed-steel abrasive known by the trade name of "diamond-grit steel emery." It is especially useful for sandblast work and for grinding marble and other stone work.

The more common natural abrasives are diamond, carbonado (or black diamond), garnet, corundum, emery, sandstone (generally quartz), and flint.

Diamond.—Diamond is the hardest and most efficient of the natural abrasives, but its high cost renders its use prohibitive except for polishing precious stones and for a few other minor purposes. In most cases diamond chippings, or borts (impure diamonds), are used. The principal diamond mines are in South Africa.

Carbonado.—Carbonado (also known as "black diamond") is a very hard and tough substance. It

is especially useful for drill points, grinding-wheel dressers, and saw teeth for cutting stone and where severe shocks must be withstood. It is found principally in Brazil.

Garnet.—Garnet is a hard, reddish, natural material. It is useful in manufacturing garnet paper and cloth for finishing hardwood articles such as tool handles. As a rule it is too soft for grinding wheels for iron and steel. The principal garnet deposits in this country are in northern New York State, New Hampshire, Connecticut, North Carolina, and Pennsylvania. Garnet is also found in commercial quantities in Czechoslovakia and a few other countries. Purer forms of garnet are classified as precious stones and are used for settings in jewelry.

Corundum.—Corundum is another hard natural mineral. Because of the difficulty encountered in preparing it for use, it has never been mined extensively for an abrasive in this country. The most important corundum deposits in the United States are in North Carolina, northern Georgia, and central Montana.

Emery.—Emery is an impure form of corundum. It is brownish in color and very hard. Before the advent of manufactured abrasives, it was the most important abrasive used in grinding wheels and for rapid-cutting powder. The main deposits in our country are in Chester, Mass., and Peekskill, N. Y. It is found extensively on the island of Naxos in the Grecian Archipelago and in Asia Minor.

Sandstone.—Sandstone is very common and is widely distributed. It is the abrading element in all common natural grindstones, whetstones, scythe stones, and natural sandblast materials.

Flint.—Flint is an impure quartz. Formerly it was used to a certain extent for high-grade sandpaper (flint paper), but since the advent of manufactured abrasives its use for this purpose has been limited.

Natural Sharpening Stones.—Among the most common uses of abrasives are for sharpening stones and grinding wheels. Stones have been used for sharpening since long before the dawn of recorded history. The earliest tools used were probably pieces of flint or other hard stone and were sharpened by rubbing them against pieces of flat sandstone. Relics of stones used for this purpose have been found in the ruins of ancient countries. As tools of metal came into use, however, better methods of sharpening became necessary, and more attention was given to the subject of sharpening stones.

Sharpening Stones. Historical.—Among the first written records of the use of sharpening stones is the Biblical account in I Samuel, which reads: "But all the Israelites went down to the Philistines to sharpen every man his share and his coulter and his mattock." A cabinetmaker's tool basket dating back as far as 1490 B. C. containing an oilstone and a horn for oil has been found in Egypt. Pliny, the Roman writer, mentions oilstones from Crete and Sicily, also Spanish stones for honing razors.

The first mention of sharpening stones in this country seems to have been by the early English settlers of New England near Wollaston, Mass. Very little mention was made of the industry from that time until about 1815, when quarrying began in Arkansas, where the famous Washita oilstones are obtained. For many years the Washita stones (known as "Mississippi stones") were the standard for high-grade sharpening stones in this country. In 1825 sharpening stones began to be quarried at Indian Pond, N. H. Ever since that time this section has been noted for its "Pike" scythe stones, known and used all over the world. Early in the last century the quarrying of sharpening stones was started near French Lick, Ind. It is reported that a large consignment of Hindustan stones was shipped to England at one time and was rejected on the ground that the name was misleading because it indicated that the stones came from India. The Turkey-red oilstone also came into use early in this country and for many years was the standard by which all other similar stones were gaged. Among other important sharpening stones on the market are the German water hone and the Belgian razor hone, both of them high-grade products noted for their ability to produce a keen edge.

Nature and Production of Sharpening Stones.—All sharpening stones are composed of crystals (the abrading element), cemented together, which expose sharp cutting edges when fractured. The natural rock can be compared to ordinary cracked-stone concrete, the pieces of cracked stone representing the

crystals, and the cement the bond. The fineness, coarseness, hardness, toughness, and ability of the crystals to present new cutting edges when fractured determine the quality and usefulness of the stones.

Quarrying rock for sharpening stones does not differ in its essentials from quarying other kinds of stone,

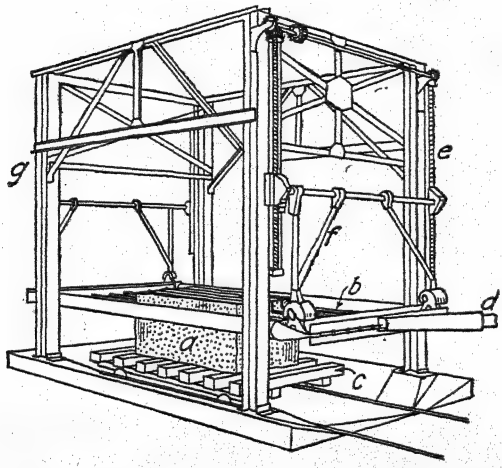

FIG. 122.—Stone gang saw. *a*. Stone block. *b*. Saw blades. *c*. Block car. *d*. Pitman. *e*. Raising screw. *f*. Suspension bars. *g*. Frame. (*Courtesy of Lincoln Iron Works.*)

except that greater care must be exercised to secure the rough blocks in shapes and sizes that can be worked with least waste. In some instances (especially with Indian Pond scythe stones) the rock is quarried in large blocks called "timber," and the individual stones are broken roughly to form from this. In other cases the rough blocks are brought directly from the quarries, embedded in plaster of Paris on saw benches, and sawed into long strips which are afterward broken to length (Fig. 122). In all cases, after the stones

are roughed out they are trued up and finished on special rubbing wheels upon which are played sharp sand and water. Saws with diamond, carbide of silicon, or carbonado teeth are sometimes used for shaping larger pieces, and small wheels are generally

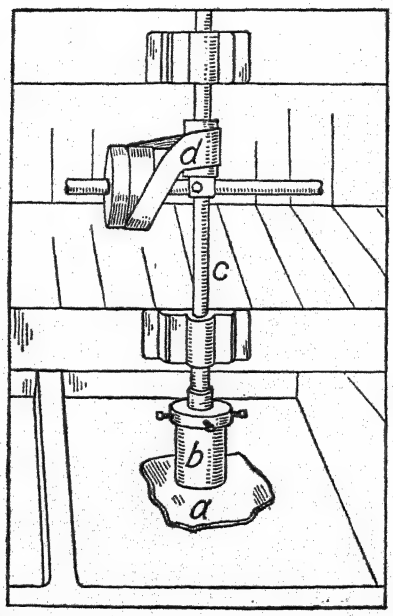

FIG. 123.—Cutting out circular grinding wheels. *a*. Natural rock. *b*. Die. *c*. Spindle. *d*. Driving belt.

cut out with revolving dies supplied with sand and water (Fig. 123).

Large natural grindstones are generally quarried to rough diameter with a circular channeler which consists of a revolving stand supporting a horizontal arm which in turn supports a steam piston drill. As the arm moves around, a circular channel is cut

by the drill in the bedrock, and the piece so blocked out is afterward loosened by wedges or with a light blast of powder underneath. The sides of the block are roughened off flat with picks, after which the block is sawed into stones of desired thickness, these, in turn, being finally trued up on a turning lathe (Fig. 124). Care must be exercised in selecting the rock

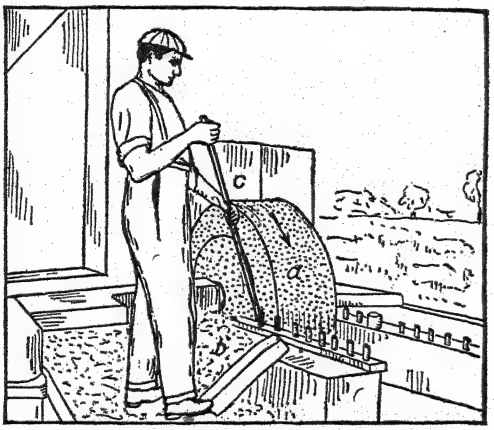

FIG. 124.—Turning large natural grindstone. *a*. Stone. *b*. Tool rest. *c*. Turning tool.

for grindstones, as it frequently contains soapstone, iron, hard spots, or seams which would seriously impair the usefulness of the finished product.

Manufactured Abrasives.—Natural sharpening stones have been largely replaced by manufactured products. But they are still extensively used for grinding paper pulp, surfacing saw and file blanks, and for grinding other articles where artificial abrasives might not be suitable. They are still in common use for ordinary sharpening in many rural sections; no

farm, however poor or remote, is without its grindstone for grinding mowing-machine knives, axes, scythes, and other common tools.

Carbide of Silicon.—Carbide of silicon was the first of the manufactured abrasives to be developed. Dr. Edward G. Acheson, an American scientist, while experimenting with carbon electrodes and a mixture of ground coke and clay in a plumber's bowl, discovered minute crystals adhering to the carbon after the mixture had fused and cooled. Supposing the compound to be carbon and corundum, he gave it the name of "Carborundum." Upon further investigation, however, the substance proved to be carbide of silicon, but the name Carborundum has been retained as a proprietary name for one particular brand of silicon carbide. The crystals proved to be extremely hard and would scratch any substance except diamond.

The possibilities of the material for an abrasive were readily seen; and it was not long before it began to be produced on a small commercial scale. At first, its use was confined to the polishing of precious stones, but as its merit became better known and the price cheapened, it was extended, until it has become universally used for practically all kinds of grinding and polishing.

The first commercial silicon-carbide plant was erected at Monongahela, Pa., in 1895. It soon became evident, however, that the success of the undertaking depended upon a cheaper supply of electric current than could be secured in that section. At about this

time the Niagara Falls power project began to develop, and the young industry was moved and established near one of the large power plants in that city. The problem of cheap supply of electric current being solved, the enterprise rapidly developed, and it was not many years before it became one of the leading industries of the country.

Silicon-carbide crystals are produced in an electric furnace of the resistance type by fusing together a

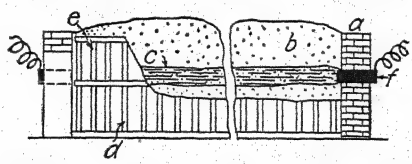

FIG. 125.—Carbide of silicon furnace. *a*. End retaining walls. *b*. Batch. *c*. Carbon core. *d*. Stationary reinforced side pieces. *e*. Removable side pieces. *f*. Carbon electrode.

mixture of 56 per cent sand, 35 per cent coke, 7 per cent sawdust, and 2 per cent salt. The sand furnishes the silicon, the coke the carbon, the sawdust renders the mass porous to allow gases to escape, and the salt helps to remove impurities.

A typical modern silicon-carbide furnace consists of an open, reinforced fire-brick structure about 45 feet long, 10 feet wide, and 10 feet high (Fig. 125). The ends are closed by fire-brick retaining walls through which carbon electrodes are adjusted to convey the current to the charge. The sides are composed of braced steel sections divided horizontally into upper and lower halves and lined with fire brick. The upper halves are again divided into smaller units which can be removed to facilitate charging and dis-

charging. When the furnace is burdened (charged), it is first filled about half full of the raw mixture. A core of ground coke is then laid through the center to connect the ends of electrodes and act as a resistance. The burden is then completed, and the electricity is turned on. A current of 10,000 amperes and 300 volts passes through the mass, causing the temperature to rise to over 4000°F., heat enough not only to melt and boil granite but also to cause it to vaporize. The current is left on for thirty-six hours during which time the impurities are burned out and the mixture is fused into hard crystals of silicon carbide. The mass is now allowed to cool, the sides of the furnace are torn down, and the crystals are removed and are ready to be crushed, cleaned, graded, and manufactured into various forms of abrasive products. The first commercial Carborundum furnace produced about a quarter of a pound of crystals per day, and the price was about $880 per pound. The present-day larger furnaces produce about eight tons of crystals in six hours, and the present price is around fifteen cents per pound.

A large percentage of silicon-carbide crystals is manufactured into sharpening stones and grinding wheels. The process consists, in general, of mixing properly selected (sized) grits with some sort of binding material, moulding it into form, and pressing, or vitrifying, the forms into a solid state. The most common of the binding materials are kaolin, hard rubber, plastics, and gum shellac. Kaolin is most extensively used for sharpening stones and smaller

grinding wheels; hard rubber and plastics are especially adapted for thin wheels that must stand up under considerable strain; and shellac is used for larger coarse wheels for heavy grinding. Silicon carbide is also extensively used for refractories for high-temperature furnace linings, where it is especially valuable. In its powdered form it is especially useful in grinding and polishing marbles, stone, glass, and other materials. It is also mixed in castings for metal stair treads and other floor covering to lessen the tendency for the metal to wear slippery.

Silicon-carbide abrasives are also manufactured and sold under other trade names as Crystolon, Carbonite, Carbolite, Carbolon, Electron, Radiac, Rexite, Staralon, Sterbon, Vulcanite, etc.

Aloxite.—"Aloxite" is the name for another manufactured abrasive. It is produced by fusing high-grade bauxite (aluminum oxide) in an electric-arc-type furnace. The furnace consists of a steel kettle about 6 feet in diameter at the top, 5 feet in diameter at the bottom, and 6 feet high (Fig. 126). On either side of the kettle is a strong lug for hoisting and handling. Two large carbon electrodes supplied with electric current from above project downward into the kettle to furnish the arc. Before the furnace is started, a layer of calcined bauxite is placed in the bottom. On top of this is arranged a path of ground coke to make connection between the ends of the electrodes. When the current is turned on, an arc is struck, and intense heat is generated, melting and burning the impurities from the bauxite and converting it into aluminum

oxide. As the process continues, fresh bauxite is added as fast as the melting and purifying take place, until the kettle is full. The electrodes either burn off or are gradually raised to accommodate the height of arc to the level of the melting zone.

After the mass (now a solid pig of aluminum oxide weighing over ten tons) is cooled, it is dumped out of the kettle and broken into pieces with a "skull cracker" (a heavy iron ball dropped from a considerable height) and is ready for further crushing, screening, cleaning, grading, and manufacturing into abrasive products. Aluminum-oxide crystals are not so hard as silicon-carbide crystals, but they are tougher and more durable and more economical for grinding tough steels and other tough metals.

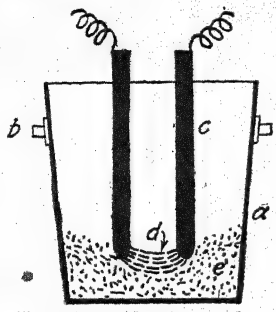

FIG. 126.—Aluminous abrasive (aloxite) furnace. *a.* Sheet-steel crucible. *b.* Lugs. *c.* Carbons. *d.* Arc. *e.* Batch or charge.

Federal Aluminous Abrasives.—Federal aluminous abrasives is the trade name for a product of the electric furnace obtained from calcined bauxite. The furnace is the same in principle as the aluminum-oxide furnace but somewhat different in design (Fig. 127). The furnace is single phase of the arc type, with two carbon electrodes, one above and one below. The process consists of charging the furnace burden into a water-cooled steel shell. The burden largely forms its own refractory lining within this shell. The process of

making the pig requires about six hours. The charging of the furnace is continuous for thirty-four hours, the raw materials being thrown in as fast as they melt down, two hours being spent in what is known as "boiling down the pig."

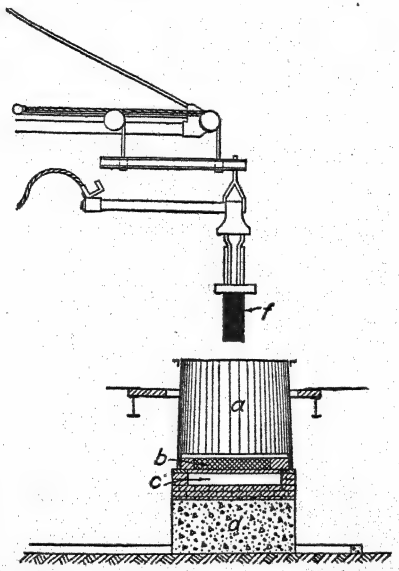

FIG. 127.—Aluminous abrasive furnace. *a*. Refractory lined shell. *b*. Carbon electrode. *c*. Sweeps. *d*. Concrete foundation. *f*. Carbon electrode. (*Courtesy of Federal Abrasive Company.*)

The proportions of the burden depend upon the analysis of the raw materials. Ordinarily about 1,000 pounds of calcined bauxite, 36 pounds of coke, and 50 pounds of steel borings are used. When the power is shut off, the pig is molten from top to bottom and must stand from six to eight hours to solidify. It is then lifted from the furnace by a traveling crane and conveyed to the cooling beds. The processes

of crushing, grinding, and grading are the same as those used for aloxite.

Alundum.—"Alundum" is another trade name for aluminum oxide produced in an electric furnace, from bauxite. A common form of this product is seen in the so-called "India oilstone" for sharpening edged tools. It is reddish in color, and the stones generally have oily surfaces from the oil which is mixed with the bond when they are pressed into form.

Norbide.—A new artificial abrasive has recently been developed in the laboratories of one of our large abrasive companies. It is a boron-carbide product and is known by the name of "Norbide." Its raw materials are boric acid and petroleum coke (carbon). The boric acid is first made anhydrous and comes out in the form of a glass (pure boron oxide). This is fused with the coke in an electric furnace at a temperature around 5000°F. In the process the oxygen is displaced by carbon, resulting in pure boron-carbide crystals.

It is claimed that the material is next to diamond in hardness, and it has already found an important place as an abrasive for grinding and lapping dies, sharpening cutting tools, and grinding other articles made of cemented tungsten and tantalum carbide where ordinary abrasives have failed. In its moulded form it is having widespread use in linings for nozzles for sandblast work and extruding dies. It also has large possibilities in the metallurgical field as an alloying material and a scavenger agent.

The supply of borax is obtained at the present time from the famous deposits of Death Valley, California.

Abrasive Terms

abrading—Wearing away any substance with an abrasive.

aluminous abrasive—An abrasive produced by fusing aluminum oxide.

bauxite—A high grade of claylike ore. Aluminum oxide.

bond—Any substance used to cement the crystals or grit together in an abrasive.

buhrstone—A circular grindstone revolving horizontally on another stone and used for grinding cereals, paints, ores, and fertilizers.

burden—The charge of raw materials in a furnace.

calcined bauxite—Bauxite from which the water has been driven off by heating.

carbofex—Carbide-of-silicon product used for refractories.

coulter—A knife or wheel on a plow to cut the sod when plowing.

grain—The quality of an abrading stone.

grit—The crystals in an abrasive.

hone—A fine-grained sharpening stone used more especially for razors.

India oilstone—Artificial sharpening stone composed of crushed alundum crystals and a bond.

Indian Pond stone—Sharpening stones from Indian Pond, N. H.

kaolin—A fine quality of clay (china clay) used for bond.

millstone—Same as buhrstone.

pulpstone—A circular grindstone used for crushing or grinding wood into pulp.

sandblast—A strong blast or jet of air containing a fine abrasive used for cleaning metal and other surfaces.

scythe stone—A long, slim sharpening stone made especially for sharpening grass scythes by hand.

sharpening stone—Any natural or artificial stone with grit used for putting an edge on steel tools.

silicon carbide—A substance composed of the elements silicon and carbon, produced by fusing at a high temperature.

skull cracker—A heavy iron ball allowed to drop from a height to break up, or crack, hard substances, as aloxite, rock, etc.

timber—The term applied to rough blocks of natural rock as it comes from the quarry before being shaped into sharpening stones.

vitrify—To bring a substance to the point of fusion so that it will solidify into a solid mass, as glass, the bond in an abrasive stone, the glaze on bricks, etc.

Abrasive Questions

Group I

1. What qualities must a good abrasive possess?

2. What is the first mention of sharpening stones in this country?

3. Name the principal natural sharpening-stone producing sections of the United States.

4. Why did England refuse to allow the American consignment of sharpening stones to enter the country?

5. Why must care be exercised in selecting rock for grindstones?

6. Explain how a stone saw can cut without teeth.

7. How are small circular grinding wheels formed?

8. What natural abrasive was most extensively used before the advent of artificial abrasives?

9. Where was the first carbide-of-silicon plant located in this country? Why did it move from there?

10. How did the name "Carborundum" originate?

11. Give the shape, size, and general construction of a large carbide-of-silicon furnace.

12. What was the first commercial use for Carborundum?

13. Give the raw materials used, their proportions, and the purpose of each in the production of carbide of silicon.

14. Give the amount of current generally applied, the temperature reached, and the time required for producing a batch of carbide-of-silicon crystals.

15. Describe an aloxite furnace, as to its shape, size, and operation.

16. What is the raw material for the production of aloxite?

GROUP II

17. Compare the aloxite furnace with the furnace for producing federal aluminous abrasives.

18. Explain why artificial abrasives are apt to be more nearly uniform in structure than a natural abrasive.

19. Explain why artificial abrasives can be obtained in a greater variety of grades than natural abrasives.

20. Should the bonding material in an abrasive be harder or softer than the crystals? Explain your answer.

21. How can we test for the hardness of any abrasive?

22. Why is water or oil used on a sharpening stone?

23. Explain how sandpaper is made.

24. Why is cloth better for the base of an abrasive than paper, as sandpaper?

25. What does the term "vitrify" mean? How does it apply in the manufacture of artificial abrasives?

26. What determines the form of a sharpening stone or grinding wheel?

27. How would a stone for sharpening a razor differ from one for sharpening an ax?

28. Why must a high-speed grinding wheel have stronger bond than an ordinary oilstone?

29. In what special way does the abrasive industry aid the automobile industry?

30. Explain how stone mouldings can be produced by grinding wheels.

BUILDING STONES

Historical.—Probably stones were among the earliest materials used for building purposes, first in their rough condition and afterward smoothed or cut to form to meet the needs as building construction

developed. Remains of statuary, monuments, ornaments, and various kinds of masonwork are found in the ruins of nearly all ancient countries. In some instances building feats accomplished by ancient peoples have astonished the civilized world. Huge blocks of granite, weighing many tons, were hewn from their beds and elevated to high positions by methods that are not known to the present and that would challenge the skill of our modern engineers. Often from the ruins of ancient stone buildings we obtain the most authentic information of prehistoric peoples.

Kinds of Rock.—In the study of building stones some considerations should be given to the origin of the rocks from which they are obtained. There are three general classes of rocks: sedimentary, igneous, and metamorphic. Sedimentary rocks result from the deposition of gravel, sand, or clay, generally by water, and their cementation together by lime, potash, or some other substance. Igneous rocks are the result of the consolidation of molten materials at or below the surface of the earth, and metamorphic rocks result from changes in either sedimentary or igneous rocks caused by heat, pressure, and volatile matter from volcanic centers.

Kinds of Building Stones. Limestone.—In order to understand the subject of rocks thoroughly, a study of petrology would be necessary, but for our present purpose it is sufficient to deal only with the main characteristics of some of the more common stones used for building purposes. Among these are lime-

stones, sandstones, granite, marble, and slate. Limestone, as the name implies, contains lime and is the raw material from which this commodity is obtained. It frequently has a tendency to be soft when first quarried but becomes harder after the moisture, or quarry sap, has dried out of it. This is an advantage in a way, as it makes it easier and cheaper to cut when first quarried but renders it harder and more durable in the building.

Typical uses of limestone in permanent buildings are the Grand Central Terminal in New York City, the City Hall in Chicago, the Washington Cathedral, and the Memorial Building in Milwaukee. Among the more common uses for limestone are crushed stone for road construction, concrete, in railroad ballast, furnace flux, the principal ingredient in the raw mixture for Portland cement, building stone, lime burning, soil sweetening, glass making, paper making, and the manufacture of chemicals. Although limestone is widely distributed, the main commercial deposits in this country for building stones are in Indiana, Missouri, Minnesota, and Kentucky. The largest producers for other uses are Pennsylvania and Ohio.

Sandstone.—Sandstone is sedimentary rock and is composed largely of quartz grains. Because of its gritty nature it is especially valuable for grindstones and other abrasive instruments. Formerly it was employed quite extensively for high-class buildings, but the promiscuous use of inferior stone and the advent of Portland cement and other cheaper

building materials caused its use for the purpose to be largely discontinued. The only large production of sandstone for building purposes for several years has come from northern Ohio. The light-gray sandstone from Virginia became famous in the early history of the country as the material used for the Capitol, the White House, and other government buildings in Washington. (One of these quarries, idle since about 1840, has recently been reopened.)

Brown sandstone attained national prominence about seventy-five years ago because of its use in the famous "brownstone fronts" of New York City. Many of these fronts scaled and crumbled after a few years of exposure, but others are still in very good condition. Sandstone is used extensively for millstones, grindstones, flagstones, paving blocks, crushed stone for road construction, concrete, ballast, and other purposes. The leading states in the production of sandstone in 1925 were Pennsylvania, California, Ohio, and New York. Ohio led in building stone, Pennsylvania and New York in flagstone, and California in crushed stone.

Granite.—Granite is igneous rock composed principally of a mixture of the minerals feldspar, quartz, and a smaller amount of mica. It is found in a variety of colors ranging from white through grays, browns, and greens. Because of its strength and durability and its quality of taking a high polish, it is especially valuable for monuments, statues, pedestals, columns, and high-class buildings. The lower stories of high buildings are often constructed of granite and the

upper stories of limestone, sandstone, brick, terra cotta, or concrete blocks, to reduce the cost. When terra-cotta or concrete blocks are used, they are frequently made to imitate the granite so closely that it is difficult for the layman to distinguish between them. The Woolworth building in New York City offers an example of this type of construction. Because of its great strength and durability, granite is also adapted for heavy abutments, piers, and large building foundations. The leading granite-producing states at the present time are Massachusetts, Vermont, California, North Carolina, and Maine. The famous quarries of Quincy, Mass., which are among the leading sources of monumental granite, furnished the blocks for the Bunker Hill Monument in 1825. The well-known obelisk (Cleopatra's Needle) in Central Park, New York, is of Egyptian granite; it was presented to the city by the Khedive of Egypt and brought over in 1881.

Marble.—Marble is crystalline, impervious limestone, which takes a high polish and is therefore especially valuable for ornamentation and other high-grade work. Its surface presents a variety of colors and designs, which are emphasized by polishing and give rise to such trade names as "milk white," "black," "blotched," "banded," "clouded," "streaked," "veined," "fossil," and others.

A great many of our important buildings are constructed of marble, among the more conspicuous being the Lincoln Memorial, the Corcoran Art Gallery, the new Agricultural Building in Washington, the Amphi-

theater at Arlington Cemetery, the Capitol at Puerto Rico, and the New York Public Library in New York City. Marble is especially valuable for interior finish, where it finds its place in wainscotings, mantels, staircases, table tops, statuary, and other uses. The staircases and the interior finish of the reading room of the Congressional Library are striking examples of its use in this connection. Like limestone it is also used in making lime and cement. and for chemical and metallurgical purposes.

Some of the most beautiful marbles come from the Apennine Mountain district in Italy, especially from the Carrara quarries, which have furnished material for statuary since the time of the Romans. In this country Vermont leads in marble production, followed by Georgia, Tennessee, New York, and Colorado.

Slate.—Slate is metamorphic rock derived from clays. It has the characteristic feature of cleaving along comparatively definite lines, which enables it to be split into slabs of any desired thickness. Slate ranges in color from red through blue, black, purple, and green. It is classified as "mill stock" and "roofing slate." Mill stock does not possess a highly developed cleavage and is used largely for blackboards, school slates, flooring, wainscoting, vats, tubs, vaults, switchboards, table tops, and the like. As a rule, mill stock is sold in the rough by the quarrymen and milled to form and finished by parties dealing in the finished product. Roofing slate must possess good cleavage and must also be hard and strong enough to resist weathering and practically free from minerals

that would cause it to disintegrate or to discolor after it has been placed on the roof. (Some fading green slates oxidize to yellow and brown tones which are well suited for certain architectural effects.) Roofing slate is used just as it comes from the cleaving process. Pennsylvania leads all other states in the production of slate, followed by Vermont, Virginia, Maine, and New York. Small quantities are also produced in California and other states.

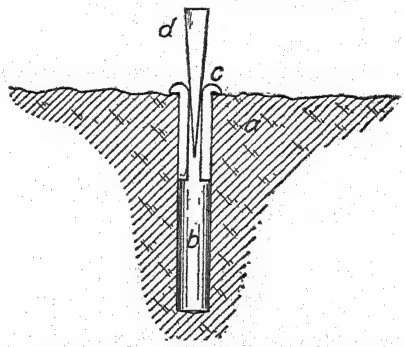

FIG. 128.—Feathers and wedge for splitting rock. *a*. Rock. *b*. Drilled hole. *c*. Feathers. *d*. Wedge.

Building stones as a rule are obtained from open pits, or quarries. The process involved in their production does not differ materially from that employed for the excavations in rock for building construction, except that the lines of drilling are more regular, and very little blasting is done because of its tendency to shatter the stones into small pieces.

Alberene Stone.—Alberene stone is a special form of soapstone of the stealite family. It is soft, gray, dense, practically moistureproof, and heat- and acid-resisting. Because of these qualities it is especially

valuable for laboratory, hospital, and industrial equipment where acids are used. Its softness permits it to be worked easily into any form desired, and it finds its way into ornaments, stair treads, landings, partitions, and other part of buildings. The only known

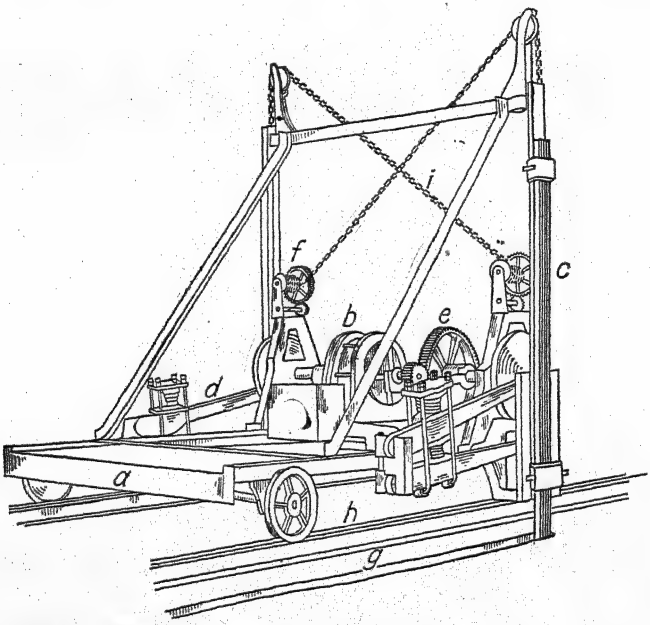

FIG. 129.—Electric stone channeling machine. *a*. Frame. *b*. Motor. *c*. Chisels. *d*. Drill-lifting lever. *e*. Gear. *f*. Windlass gear. *g*. Channel in rock. *h*. Rail. *i*. Windlass chain. (*Courtesy of Lincoln Iron Works.*)

commercial deposits of alberene stone are in Albemarle County, Virginia.

Quarrying.—Formerly all quarrying of building stones was done by hand. A series of holes was drilled along the desired plane of separation. Two "feathers" with a wedge between were inserted into each hole,

and as the wedges were driven down, the lateral pressure caused the rocks to separate (Fig. 128). The same method is used to a considerable extent today, with the exception that the drilling is generally done with power drills instead of by hand. Sometimes the holes are filled with water, and wooden plugs are driven in. The pressure of the plugs on the water splits the rocks apart. The swelling of the wood also exerts pressure.

A more modern method of quarrying building stones is by the use of special channelers which consist of a series of reciprocating chisels operating on the side of a machine moving along tracks (Fig. 129). The chisels cut a deep channel along the sides of the blocks which are afterward loosened from the bottom by undercutting, or drilling, horizontal holes and wedging. The blocks, often weighing many tons, are next hoisted to the surface by powerful cranes and transported to the mills where they are sawed into sections and planed, turned, polished, cut out by hand, or otherwise worked to form and finish.

Stone Sawing.—There are several types of stone saws in operation. The most common of these consists of a rigid bedpiece equipped with tracks for operating a low, flat car that carries the stone and holds it in position while being sawed (Fig. 122). Above the bedpiece a series, or gang, of flat, soft-steel, horizontal saws adjusted in a frame operates with a reciprocating motion. The saws themselves have no teeth but do the cutting by pressing sharp sand or steel shot in water into the stone. By this method a

large block can be cut into slabs of any desired thickness at one operation in a remarkably short period of time. A modified form of this type of saw consists of a flat steel strip with notches in its lower edge which grip the hard-steel shot and help to force it into the stone. These saws are used especially for granite and other very hard materials. Steel circular saws with inserted diamond or Carborundum teeth are also

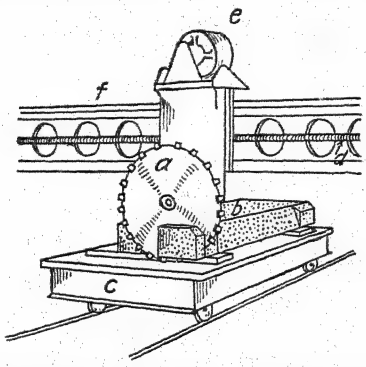

FIG. 130.—Circular stone-cutting saw. *a*. Saw. *b*. Block of stone. *c*. Block car. *d*. Feed screw. *e*. Motor. *f*. Cross-rail.

extensively used (Fig. 130). As a rule, they are employed for finishing pieces to definite dimensions or cutting special forms. Thin Carborundum wheels are also used for light, efficient work where fast cutting is an important factor. A unique type of saw for general work is the wire saw which consists of a twisted wire cable operating between pulleys a considerable distance apart. One strand runs in contact with the stone and acts as the saw, and the other passes through the air or sometimes through water for cooling. The cutting is done with sharp

sand in water the same as in the case of the gang saw. This type of saw is sometimes used in slate or other soft-stone quarries for making the vertical cuts on the sides of the blocks before they are loosened from the bottom.

Grinding and Polishing.—All saws leave the surfaces of the stones in a more or less rough condition; consequently, if they are to be smooth and polished,

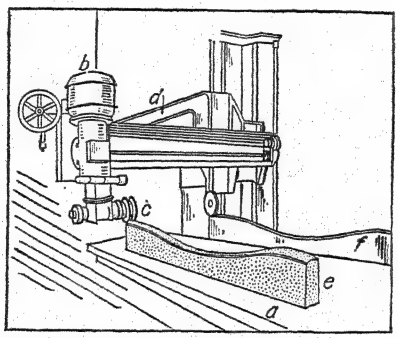

FIG. 131.—Stone-moulding-cutting machine. *a*. Table or bed. *b*. Motor. *c*. Carborundum wheel. *d*. Arm. *e*. Block of stone. *f*. Template. (*Courtesy of Patch-Wegner Company, Inc.*)

they must be planed or otherwise milled after sawing. A stone planer does not differ in principle from those used for iron and steel. In general, it consists of a solid bed upon which a table or platen for holding the stone travels back and forth with a horizontal movement. A tool is adjusted in a cross-rail above, which is attached to the housing and held in such a position that a portion of the stone is cut off as it is carried underneath by the platen. By adjusting the tool sidewise or vertically, a slab of any desired thickness or width can be obtained. The same machine can also

be used for cutting coping or mouldings by exchanging the straight tool for one having the desired form.

A more modern method of stone milling is by the use of abrasive wheels (generally carbide or silicon).

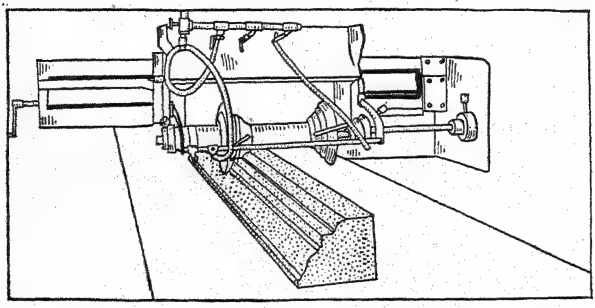

FIG. 132.—Stone-moulding machine cutting moulding with Carborundum wheel. (*Courtesy of Lincoln Iron Works.*)

The machines do not differ materially from planers except that the abrasive wheels operate on the cross-arms and do the cutting instead of steel tools (Figs. 131, 132). By this method the work can be done

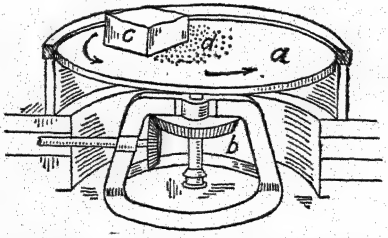

FIG. 133.—Rubbing bed for stone. *a.* Rubbing wheel. *b.* Driving gear. *c.* Stone. *d.* Sharp sand and water.

more cheaply and more accurately, and a greater variety of moulding designs can be secured. Another method of surfacing is by use of "rubbing beds" which consist of large, flat, iron disks installed to revolve in a horizontal position similar to a phono-

graph record (Fig. 133). The blocks of stone are placed on the disk with the side downward that is to be polished and held from traveling around with an arm or other mechanism which extends outward from the center. When the disks are in motion, sand and water, thrown on the surface and carried under the blocks, do the cutting. If the blocks are large, their

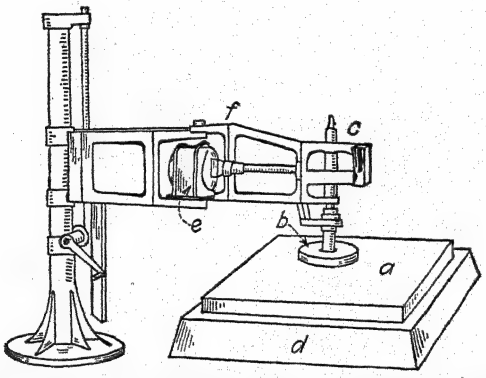

FIG. 134.—Motor-driven marble-polishing machine. *a*. Marble slab *b*. Carborundum head. *c*. Shaft. *d*. Bed. *e*. Motor. *f*. Polisher frame (*Courtesy of Lincoln Iron Works.*)

own weight is sufficient to press them against the rubbers; but if they are small, pressure is applied from above. This method of surfacing has been in use for many years and is fairly cheap and efficient for flat, ordinary work. It is giving way gradually, however, to the more modern methods of grinding.

A large percentage of stones used for buildings, monuments, etc., requires highly polished surfaces. For the most part this is done on special polishing machines. A typical machine for polishing consists of some sort of bedpiece for holding the work, over

which horizontal iron disks revolve in contact with the surface (Figs. 134, 135). At first the grinding is done with sand and water and afterward with emery powder. This gives the work a flat surface that is often sufficient for certain grades of work. If a high polish is required, however, the iron disks are replaced

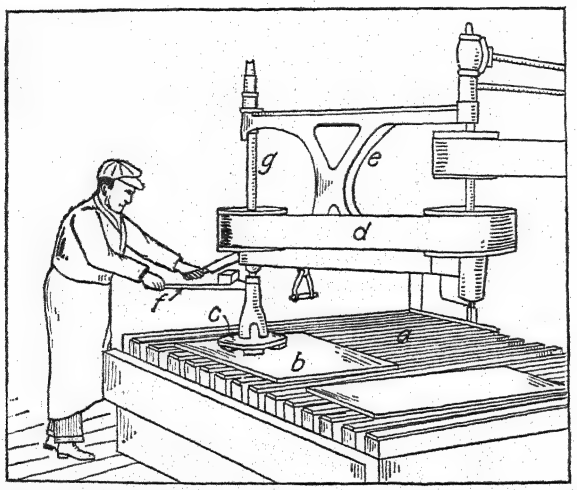

FIG. 135.—Marble-polishing machine. *a.* Polishing bench. *b.* Marble slab. *c.* Carborundum head. *d.* Lower drive belt. *e.* Front polisher frame. *f.* Handle. *g.* Front hollow shaft. (*Courtesy of Lincoln Iron Works.*)

by felt rubbing pads and the use of rouge or some other polishing compound.

The use of building stones for general construction is relatively less than it was in former years because of their high cost and the abundance of substitutes available, as concrete, bricks, and terra cotta. But they will always be in demand for massive artistic buildings and monuments where beauty combined with strength and durability are the main considerations.

Building-stone Terms

alberene stone—A soft, dense, gray soapstone.

blotched—Spotted effects, especially on stone and other marble.

brecciated—Rock composed of angular fragments held together in a matrix. It produces very beautiful effects when polished. Applied to certain figures in marble.

brownstone—Sandstone of a reddish color due to the presence of iron oxide, formerly used extensively for buildings.

diamond-tooth saw—A circular saw for cutting stone with points of the teeth of pieces of diamonds.

feather—A small piece of steel flat on one side and oval on the other, inserted each side of a wedge in a drill hole for splitting rocks.

flagstones—Flat slabs of stone, generally bluestone, used for sidewalks.

granite—A crystalline rock composed largely of quartz mixed with other minerals. It takes a beautiful polish.

igneous rocks—Rocks formed by the fusing of minerals below the surface of the earth and afterward solidifying.

marble—Lime rock that has solidified in crystalline form. Takes a fine polish.

matrix—The rock in which a fossil or mineral is embedded.

metamorphic rocks—Rocks resulting from changes in other rocks generally by heat, moisture, or crystallization.

mill stock—A term applied to rough slabs of slate generally for use as blackboards, floors, switchboards, etc.

petrology—The science that treats of the origin, occurrence, and structure of rocks.

quarry—An open excavation in the earth generally for obtaining building stones, slate, marble, or paving stones.

roofing slate—Formed flat pieces of slate that are used for covering, similar to wooden shingles.

sandstone—A rock consisting of sand grains held together by a cement, as silica, iron oxide, or calcium carbonate.

sedimentary rocks—Rocks resulting from the cementing together of sand, clay, or other materials that have been deposited by bodies of water.

serpentine rock—A rock generally having a dull green color and often spotted or mottled, resembling the spots of a serpent's skin.

slate—A dense, fine-grained rock produced by the compression and solidifying of clay.

soapstone (talc)—A soft stone with a soaplike feeling.

Building-stone Questions

Group I

1. What is meant by building stones?

2. Name the more common kinds.

3. What is meant by the study of "petrology"?

4. Name the three general classes of rocks, and explain how each class is formed.

5. What famous granite monument came to New York from Egypt and now stands in Central Park? Who presented this to the city?

6. Explain the action of the feather and wedge in rock quarrying.

7. Explain how wooden plugs can be used in quarrying rocks.

8. Where are some of the most important marble quarries in the United States?

9. Explain the action of rock channelers.

10. Name some very important buildings constructed mainly of the following stones: granite, marble, limestone.

11. Name the principal marble-producing state. Name the next two most important producing states.

12. What famous marble comes from the Apennine Mountain district of Italy? For what has this marble been used since the time of the Romans?

13. Explain two methods by which stone moulding can be cut out by machines.

14. Why are the lower courses of some buildings constructed of building stone and the upper of terra cotta?

Group II

15. What state is called the "granite state"?

16. What objection is there to the use of high explosives in quarrying building stone?

17. Give reasons why flat gang saws for stone are generally of mild steel.

18. What must be the nature of the sand or other grit used for stone sawing? Explain your answer.

19. What evidence have we that the art of stone cutting was developed in very early times?

20. Of what use is water in the process of sawing stone with flat straight saws?

21. How is Carborundum used in the construction of stone saw teeth?

22. Give reasons why stoneworking mills are sometimes located in the large cities instead of at the quarries.

23. Why are stones good for foundations? Explain why stones are used less for foundations than formerly.

24. Explain why granite presents a variety of colors when polished.

25. Give reasons why marble is especially adapted for high-grade interior finish.

26. What is meant by "flagstone"? Why are flagstones used less now than in former years?

27. Mention several places where you have seen marble used for interior finish.

28. What particular characteristic does slate possess that makes it easy to work into thin, flat pieces for roofs?

29. In some parts of the country we see stone walls used for fence. Give two reasons why this practice has been followed.

30. Give uses for stone and rock other than for concrete and building purposes.

GLASS

Historical Sketch.—Tradition tells us that at one time a merchant ship laden with nitrate was wrecked on the Phoenician coast and some of the cargo washed ashore. Afterward the sailors found transparent stones where their camp fire had been. Some of the nitrate had mingled and fused with the sand on the beach and formed crude glass. Whether or not the story is true will probably never be determined. It is certain, however, that the Phoenicians were among the earliest of enterprising peoples and that raw materials for glass making existed in abundance in their country.

Glass ornaments were known and used by the Egyptians many years before the Hebrew exodus, and glass articles found in the excavations of ancient cities of Asia Minor prove that these peoples also knew and used the material in very early times. Before the time of Pliny, the Roman writer (the first century A. D.), glass utensils were made and used in France, Spain, and Italy. The art was probably brought to Britain by the early Roman invaders.

Glass making in Europe, however, like all other industries in the Middle Ages, developed very slowly because of the aversion of the better classes to any kind of manual labor. Work with the hands was deemed fit only for serfs or slaves. Yet so important was the art of glass making that at one time a court decree was issued to the effect that only nobles could engage in the industry and that under no circumstances should the occupation be called a trade.

Because of its great cost, glass making for many years was confined to the production of ornaments and a few utensils. It is reported that one of the Roman emperors paid a sum equal to $100,000 for a glass cup with handles.

In the thirteenth century flat glass (probably made by casting) began to be used for cathedral windows, and rich nobles eventually employed it in their castle windows, instead of oiled paper. For a long time it was very precious, and owners upon taking a journey often took the window panes out of the frames and locked them up to prevent them from being damaged or stolen while they were away.

The glass-making industry was brought to America by the early English settlers. It is claimed that the first plant was established in Virginia not long after the settlement of Jamestown. Other factories sprang up in different parts of the Colonies as the population increased. Long before the American Revolution window glass, glass bottles, and glass dishes were made in Massachusetts, Connecticut, New Jersey, Pennsylvania, and elsewhere.

For a long time after the Colonies became free, the industry developed very slowly because of the unequal struggle with foreign competition. As late as 1883 no general directory of glassworks existed in the United States. But during the last decades of the past century economic conditions changed, and the demand for American-made glassware greatly increased. This, together with the advent of the automobile and the enormous increase in the use of glass for building

construction, has placed the industry among the foremost of American enterprises.

Before the World War, Germany, Belgium, and other European countries furnished practically all of the world's supply of optical glass and photographic plates. After the supply was cut off, however, necessity compelled the United States to give attention to the matter, with the result that there have been developed in this country processes for the production of high-grade optical glass that place us among the foremost producers of the world.

Common Kinds of Glass.—At the present time three general kinds of glass are produced: soda-lime, lead, and borosilicate glass. Soda-lime glass is the commonest and cheapest to produce. It is used extensively for plate glass, common window glass, automobile construction, common containers, ordinary glassware, electrical work, etc. Lead glass is more expensive. It is used largely for art glass, tubing for radio bulbs, electric light bulbs, cut glassware, and optical glass. Because of its brilliance, clearness, and toughness it is especially suited for high-grade ware. Pyrex is the principal representative of the borosilicate group. It is produced from a batch high in silica and boric acid. Its principal features are toughness and resistance to heat. For these reasons it is especially valuable for cooking utensils, laboratory apparatus, and other articles where these qualities are of importance.

There is a variety of ingredients and proportions that can be used in the batches for nearly all kinds

of glass. They differ with the requirements of the finished product, the materials at hand, and the individual opinions of the manufacturers.

The following are a few typical batches:

Windshield Glass	Lb.	Oz.	Average Common Window Glass	Per Cent
Sand	13	15	Silica	73.25
Soda	4	8½	Lime	12.50
Limestone	4	1¾	Soda	12.50
Cullet	5	3½	Alumina	0.75
			Other ingredients	1.00

Common Milk Bottles	Lb.		Lb.
Sand	1,000	Borax	20
Lime	370	Feldspar (flux)	60
Salt cake	5	Coloring matter	Trace
Cullet	900		

In addition to the regular raw ingredients, a considerable percentage of cullet (old glass or waste glass from former melts) can be used in nearly all batches. For a good grade of ware the cullet must be selected with care. This is especially true of optical glass, as the slightest imperfection may deflect the rays of light and render the glass useless for optical purposes.

The ordinary soda-lime window and bottle glasses make up by far the greater part of over $400,000,000 worth of glass manufactured in the United States annually. For such glass the raw materials are principally sand, lime—either raw or calcined—and soda ash, a form of carbonate of soda such as may be obtained by heating ordinary washing soda to drive off its water.

Lead glass contains lead oxide in place of lime and more or less potash in place of soda. It may contain 25 to 50 per cent or more of lead. Lead gives glass brilliance and makes a high polish possible in ornamental articles of cut glass. Lead glass is also more readily annealed and less likely to break after heating, and for that reason among others lead glass alone was used until recently for making incandescent electric lamp bulbs.

The third important group of glasses with respect to chemical composition consists of the borosilicate glasses, which contain borax or boric acid, or both. These glasses were first made commercially some forty years ago; they are valuable chiefly on account of their low expansion coefficient and resistance to dissolving action of water and chemicals.[1]

Types and Operation of Furnaces.—There are two general types of glass furnaces in common use: the tank furnace and the pot furnace. The tank furnace is the more economical of the two and is always used when mass production is the objective and when the product required is not of the highest quality. A typical tank furnace consists of a rectangular, reinforced, masonwork structure lined with large fire-clay blocks (Fig. 136). It has a low arched roof of silica bricks. One end is generally semicircular (the working end), and around it are located the work holes, or "tuiles." (In modern practice, automatic feeders are largely used which appear to close off the work holes entirely.) On either side, generally at the bottom, are regenerative chambers for preheating the fuel

[1] Courtesy of Dr. E. C. Sullivan, Corning Glass Works.

gases before they are used for combustion. Ports in the side walls just above the bath level admit the flames, which are deflected to the surface of the bath by the arched roof. The interior is divided transversely by a partly submerged bridge (a fire-clay bar) or by fire-clay floats into two unequal compartments. The larger one is for receiving and melting the batch, and the smaller one for collecting the molten glass.

The batch ingredients are introduced at the larger, or melting, end through an opening called the "dog

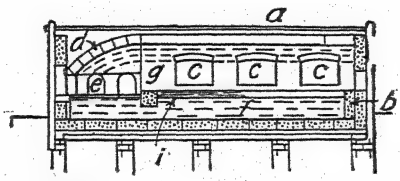

FIG. 136.—Tank glass furnace. *a*. Reinforcing rod. *b*. Refractory tank lining. *c*. Ports. *d*. Arched roof over collecting end. *e*. Collecting opening. *f*. Batch. *g*. Bridge. *i*. Gall.

house." As the melting takes place, the molten batch flows under the bridge or floats to the working end. The gall (the impurities, or scum, that rise to the top) is held back by the bridge in much the same manner as dross is pushed aside on the surface of molten lead with a ladle or stick. As the molten glass is taken from the collecting end, fresh batch materials are added to the charging end, thus keeping the level of the molten glass in the tank as nearly constant as possible.

The largest tank furnaces are about 140 feet long by 30 feet wide by 5 feet deep (inside measure) and have a capacity of about 1,800 tons. If the glass in one of these tanks should be drawn into single-thick-

ness window panes 12 inches wide and the panes placed end to end, they would extend over a distance of 600 miles, or from New York to Cleveland. The fuel generally used is producer gas, and the temperature required is from 2200 to 2800°F. When a large furnace is to be started, from two weeks to a month is required for drying and heating before glass can be melted ready for working. Once started, however,

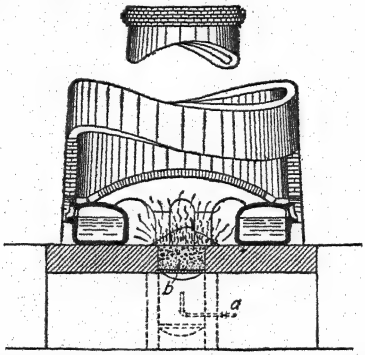

FIG. 137.—Circular-pot glass furnace, coal fired. *a*: Air pipe. *b*. Furnace, (*Courtesy of Corning Glass Works.*)

such furnaces never stop except for repairs or some other special reason. In general, tank furnaces are used for the production of glass for window panes, automobile wind shields, ordinary bottle containers, milk bottles, fruit jars, common glassware, electric light bulbs, and other articles where large quantities of medium or low-grade glass are required.

Pot furnaces are of two general types: the circular and the rectangular. The circular type consists of a dome-shaped, reinforced, fire-brick structure covered with a large, conelike brick curtain to conserve the

heat and to convey away the products of combustion (Figs. 137, 138). The outer walls contain from eight to twenty arched tuiles (according to the size of the furnace) through which the pots are introduced and the glass worked. In the central portion of the floor are two large ports through which the fuel gases enter and the waste gases escape. Regenerative chambers

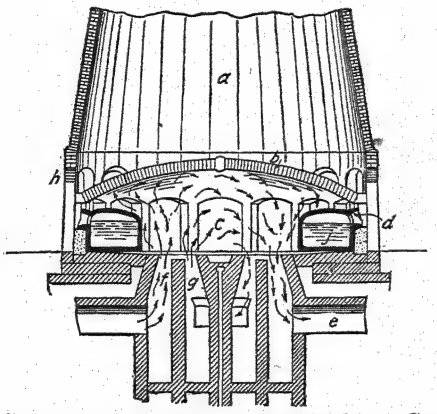

FIG. 138.—Circular-pot glass furnace, gas fired. *a*. Curtain wall. *b*. Cap. *c*. Pot opening. *d*. Pot. *e*. To regenerative chamber. *f*. Hot-air inlet. *g*. Gas port. *h*. Air port. (*Courtesy of Corning Glass Works.*)

are installed on either side for preheating the fuel before combustion. When the furnace is in operation, the pots are located just inside the doors with their mouths, or openings, projecting outward to enable the operator to do the charging and collect the glass. The flames shoot upward from one port at a time and strike the arched roof, from which they are deflected to the pots, and the waste gases pass out through the other port to the regenerative chambers. In normal operation the dampers are switched about

every thirty minutes to keep the temperature as nearly uniform as possible. The time required for melting is from twenty to twenty-four hours, and the temperature is the same as that required for the tank furnace.

Rectangular-pot furnaces do not differ in their essentials from the circular-pot type, except that they are rectangular in form instead of round. The larger sizes are about 50 feet long by 12 feet wide by 5 feet

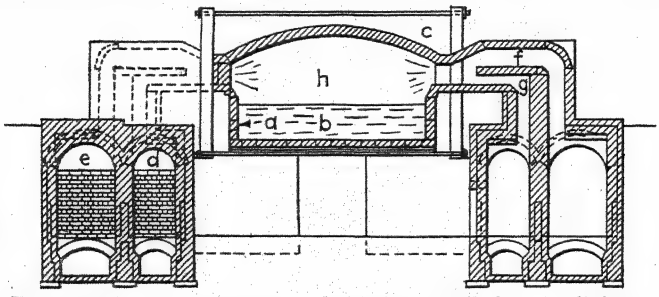

FIG. 139.—Rectangular glass tank furnace. *a*. Refractory lining. *b*. Molten batch. *c*. Arched roof. *d*. Checker work for gas. *e*. Checker work for air. *f*. Air duct. *g*. Gas flue. *h*. Gas flame. (*Courtesy of Harbison-Walker Refractories Company.*)

deep and will accommodate twenty pots—two rows of ten each. The gas for fuel enters through end ports, and the flames describe an arc as they play about the pots back and forth through the length of the furnace. Arched doors are constructed in the sides opposite the pots to allow for charging and discharging. As in the circular type of furnace, regenerative chambers are installed with each unit for conserving the heat (Fig. 139). These furnaces are used most extensively for the production of plate glass.

As the science of glass making becomes better understood, however, the tendency is to do away with pot furnaces and substitute tank furnaces in their

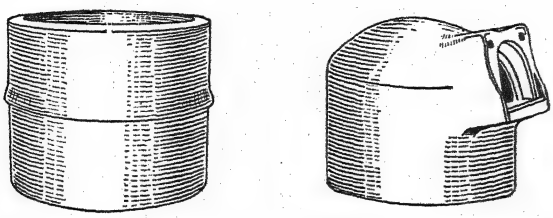

FIG. 140.—Glass-melting pots.

places, because of their cheapness and greater efficiency. Pot furnaces are not only more expensive to construct and operate than tank furnaces, but they also consume larger quantities of fuel. This, together with the high cost of the pots, makes their use prohibitive except for special high grades of glass. In the case of optical glass the pots are used only once. The melts are allowed to cool in the pots, after which the pots are broken down to remove the glass and are a total loss except as grog to mix with a fresh clay for new pots. Even the best grade of pots for other high-quality glass will stand only from thirty to sixty heats before they must be replaced. There are three general kinds of pots in

FIG. 141.—Tamping clay for glass pots.

common use: the plain, open type; the closed type with removable cover; and the closed type with the hood and a neck, or boot, at one side for receiving the batch and working the glass (Fig. 140).

Lehrs and Other Annealing Furnaces.—Molten glass, like molten iron and steel, when cooled under ordinary conditions solidifies and becomes rigid on the surface before it does in the interior. This results in interior stresses that render the glass brittle and cause it to shatter at a slight shock. To overcome this condition the ware is passed to annealing furnaces while still hot and allowed to cool very slowly at a uniform temperature throughout. As a rule, the better the quality of the glass the longer the time required for annealing.

Annealing furnaces are of two general types: the intermittent and the continuous. The intermittent type consists of a closed, fire-brick oven supplied with a special hearth and a furnace for providing heat. The oven is first heated to the proper temperature, the ware is placed on the hearth, and the doors are closed. The draughts are then regulated until the oven and its contents slowly fall to the same temperature as the surrounding air. This method of annealing is slow and expensive and is used only for special high-grade glass. The modern continuous type of lehr consists, in general, of a long, tunnel-like structure with furnace attachment (Fig. 142). It is so arranged that a high temperature can be maintained at one end and gradually reduced as the other end is approached until it is the same as that of the

surrounding atmosphere. An endless conveyor is installed in the interior and operates from one end of the lehr to the other. The ware, still hot, is placed in the mouth, or receiving end, on the conveyor and moves slowly along until it reaches the other end thoroughly annealed.

The nature and thickness of the ware determine the size of the lehr and the time required for annealing.

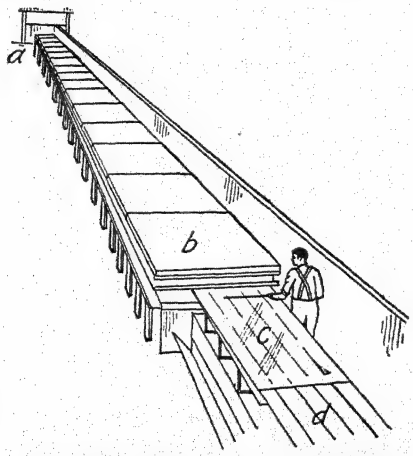

FIG. 142.—Lehr. *a.* Receiving end. *b.* Discharging end. *c.* Glass. *d.* Table. (*Courtesy of Libbey-Owens Glass Company.*)

Lehrs for milk bottles, fruit jars, and other ordinary ware range in length from 75 feet upward and require from two to four hours for annealing. Those for plate glass run as high as 800 feet long and require five hours or more for the process.

Making Common Window Glass.—There are four general methods of forming articles from molten glass: drawing, pressing, rolling, and blowing. When the blowing method is used, the glass behaves very much

like soap suds when blown into bubbles, except that it hardens into form when cooled. Ordinary window panes are produced either by drawing the glass out flat or by blowing it into straight cylinders and afterward cutting the cylinders lengthwise and flattening them out. In the flat-drawn process an iron bar, called the "bait," is lowered sidewise into the molten

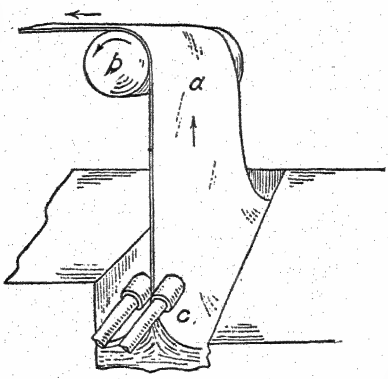

FIG. 143.—Drawing flat glass. *a*. Sheet of plastic glass. *b*. Rolls. *c*. Molten glass.

glass, which adheres to it. The bar is then lifted out horizontally, drawing molten glass with it, and is passed over a large roller that spreads the glass out into a thin sheet (Fig. 143). It is next passed through a lehr for annealing and on to a table, where it is cut to size.

A more recent process of producing flat window glass is with an upright drawing machine. In this process a horizontal bait lifts a web of plastic glass from the tank and delivers it to pairs of asbestos rolls, which smooth the surfaces and propel it upward until

it is sufficiently cooled and hardened for handling. As the sheet emerges from the top of the machine, it

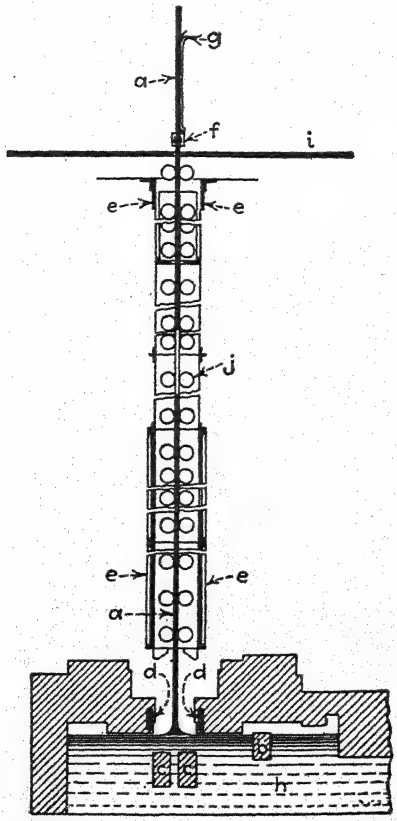

FIG. 143*a*.—Machine for drawing flat window glass vertically. *a*, *a*. Sheet of glass. *b*. Skim bar. *c*, *c*. Draw bars. *d*, *d*. Water coolers to chill the sheet. *e*, *e*. Machine case. *f*. Cut-off wire. *g*. Edge cut off. *h*. Molten glass. *i*. Cut-off floor. *j*. Asbestos rolls. (*Courtesy of Pittsburgh Plate Glass Company.*)

is cut to convenient size and is ready to be cleaned and worked up into commercial sizes for shipment (Fig. 143*a*).

Cylinder window-glass blowing has become practically obsolete. In the practice vertical cylinders of glass were blown and afterward cut to size and flattened out (Fig. 144).

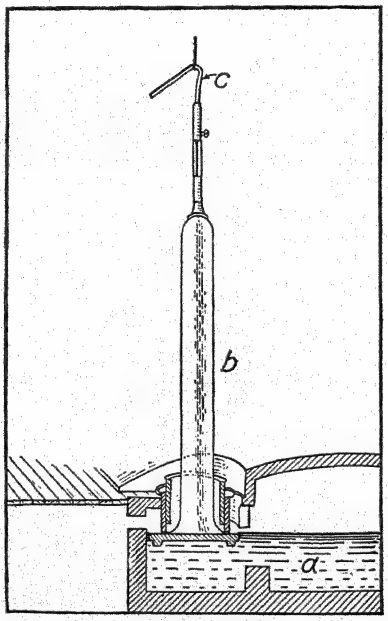

FIG. 144.—Blowing glass cylinder, for flat glass, by machine. *a*. Tank of molten glass. *b*. Glass cylinder. *c*. Air pipe. (*Courtesy of Libbey-Owens Glass Company.*)

The most important recent achievement in glass production was the casting of a huge mirror at Corning, N.Y., 200 inches in diameter and 2 feet thick, weighing 20 tons, which is to be used as the reflector for the largest telescope in the world. Boro-silicate glass was used and special equipment had to be installed for handling the materials. Annealing required eleven

months and it will be a number of years more before the grinding and polishing are finished and the mirror is ready for use.

Plate Glass.—Formerly plate glass, as a rule, was produced in a rectangular-pot furnace. The batch in each pot was just large enough to furnish glass for a workable sheet at one melting. When the glass was ready for pouring, the pot was removed from the furnace, and its contents poured out on a flat iron casting table and rolled flat with a heavy iron roller (Fig. 146). Raised strips, or cleats, at the edges of the table supported the ends of the roller and determined the thickness of the glass. The sheets, while still hot, were passed to the lehrs and annealed. As they came from the casting table their surfaces were more or less uneven and otherwise imperfect—qualities that would interfere with clearness of vision. Fortunately this condition affected only the surface and could be remedied by grinding and polishing.

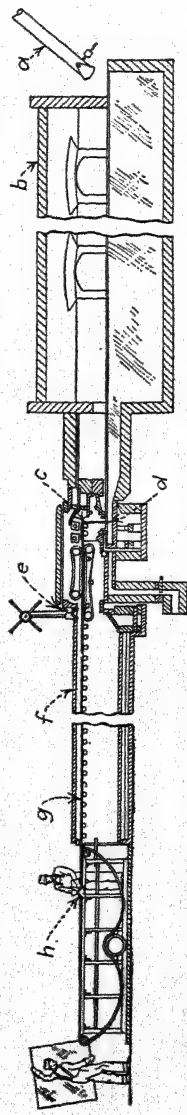

FIG. 145.—Combination glass furnace, lehr, and cutting table. *a.* Batch chute. *b.* Furnace. *c.* Bending roll. *d.* Width-maintaining knurls. *e.* Sheet starting bar or bait. *f.* Lehr. *g.* Ribbon of glass. *h.* Cutting table. (*Courtesy of Libbey-Owens Glass Company.*)

The grinding was done on large flat iron wheels revolving in a horizontal position. Smaller flat horizontal iron wheels, or runners, installed above the larger wheels rubbed on the surface of the glass and did the grinding (Fig. 147). The plates were brought

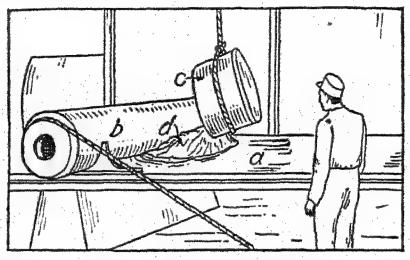

FIG. 146.—Older method of casting plate glass. *a.* Casting table. *b.* Roller. *c.* Pot for molten glass. *d.* Plastic glass.

from the lehr and embedded in plaster of Paris on the larger wheels. At first, coarse sand and water were thrown on the glass under the runners. But as the process continued, finer sand and eventually emery powder were used until all the irregularities were ground out, and the surface was perfectly flat. The

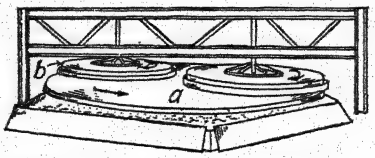

FIG. 147.—Polishing plate glass. *a.* Rubbing bed. *b.* Rubbers.

sheets were next polished on a special polishing machine which was similar in principle to the grinding machine, except that the runners were smaller and were shod with felt buffing disks instead of iron. Red oxide of iron, or rouge, was used for the polishing abrasive, and

the process was continued until the glass was perfectly smooth, clear, and brilliant.

In recent years, especially since the automobile industry created such a demand for plate glass for windshields and windows, not only are special pot furnaces being employed but large tank furnaces are rapidly coming into use as more economical. When the pot furnace is used, the molten glass is poured out and passed between two heavy iron rollers that flatten it out and give it uniform thickness. (The thickness is determined by adjusting the distance between the rolls.) In the use of the tank furnace a rough continuous sheet of glass is drawn from the tank (Fig. 143) and passed between rollers in similar manner to that for the pots.

The more modern grinding machine consists of a series of large metal disks shod with iron and mounted in a horizontal position over a flat, moving table on which the glass is embedded. The disks revolve at high speed and under heavy pressure. Sand and water do the grinding the same as in the former practice. As the table passes from one disk to another the sand is changed and becomes finer and finer until at the end it produces a smooth, flat, velvety surface. Polishing is done with revolving disks similar to those used for grinding but shod with thick felt pads instead of iron and with rouge for the polishing agent instead of sand. After polishing, the sheets are put through a bath of muriatic acid to remove any traces of rouge or plaster and are ready to be cut to size and packed for shipment.

A large per cent of the original glass is wasted in grinding, but up to the present time no successful method has been devised to avoid this waste. The larger sizes of plate-glass sheets run as high as 12 feet wide by 20 feet long and over, and the thickness varies from ⅛ to 1½ inches or more. "Bent" glass is produced by placing flat sheets on moulds made to the desired shape or radius and subjecting them to a temperature sufficient to allow the glass to soften and settle to the shape of the mould. It is then carefully annealed by the same process as flat plate and window glass.

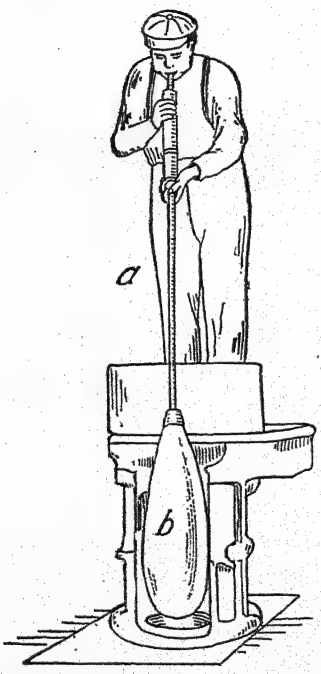

FIG. 148.—Blowing glass by mouth. *a*. Blow pipe. *b*. Bubble of glass. (*Courtesy of Corning Glass Works.*)

Blowing into Moulds and Pressing.—Most of the common hollow and irregular ware is formed by either blowing or pressing the molten glass into moulds. High-class art pieces are generally blown or moulded free-hand by specially skilled artists (Fig. 148). Cut-glass ware is first blown or moulded into blank forms and afterward cut to design and polished on grinding and polishing wheels. So-called "shatter-proof" glass is made by cementing sheets of clear plastic between

sheets of regular glass. The surfaces of the glass and plastics are treated with certain chemicals, after which the plastic is inserted between the other sheets, and the assembly is subjected to heat and pressure. This cements the layers together and gives the appearance of a single piece. Wire glass is made in three different ways: (1) by rolling out a sheet of glass and afterward pressing wire netting into its surface while

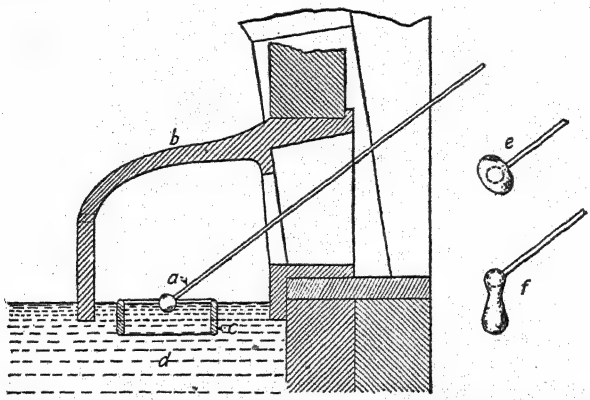

FIG. 149.—Cross-section through boot in glass furnace. *a*. Collecting rod. *b*. Boot. *c*. Ring. *d*. Molten glass. *e*. Ball of plastic glass. *f*. Plastic glass ready for mould. (*Courtesy of Corning Glass Works.*)

it is still plastic. It is afterward rolled smooth again; (2) by rolling out a thin sheet and laying wire netting upon it and afterward pouring and rolling another thin sheet on top of the wire; (3) by stretching the wire netting just above the surface of the casting table and pouring and rolling the plastic glass around it. Figured flat glass, as Florentine, cobweb, and ribbed, is produced by rolling the sheets on a flat casting table in the surface of which the desired patterns have been

worked or with a roller having designs cut in its surface.

Optical Glass.—Optical glass is in a class by itself. It is generally melted in a closed pot in a single-pot furnace. After melting, the glass goes through "fining" and stirring processes before it is annealed. The fining process consists in raising the temperature until the glass is quite fluid and holding it there until all the gases have escaped. It is then allowed to cool partially and is stirred with a special hollow burnt-clay stirring implement to remove striae and make the glass perfectly uniform. It is then annealed in a special annealing furnace and is ready to be reheated and rough moulded to desired forms for grinding and polishing. The annealing process requires several days and sometimes weeks if the best results are to be obtained.

Colored Glass.—Colored glasses are generally produced by adding certain metallic elements to the batches either before or during melting. Almost any color or combination of colors can be secured with the proper elements. This branch of the industry, however, requires a thorough knowledge of chemical reactions and a high degree of technical skill. The following are combinations for a few of the more common colors:

Red.—Produced by adding copper (cuprous) oxide, or selenium (gold chloride produces a brilliant ruby).

Blue.—Produced by adding cobalt (in soda-lime glass the color is a violet blue; in lead glass it is the blue of the spectrum).

Green.—Produced by adding ferrous oxide. (Because of the fact that nearly all sand and clay contain a certain amount of iron

nearly all glasses have a greenish hue in their natural state. This can be overcome only by adding some counteracting, decolorizing agent.) A small amount of chromium produces a bright green.

Yellow.—Produced by adding a small amount of uranium oxide.

Violet.—Produced by adding a small amount of manganese oxide. This element will produce colors from amethyst to deep violet.

Amber.—Produced by adding carbonaceous material, as coke, coal, sawdust, charcoal, etc., to soda-lime glass.

Black.—Can be produced by adding an excess of manganese, cobalt, or iron.

Glass Blackboards.—A recent development in the glass industry is a glass blackboard, known by the trade name of "Seloc" glass. It is produced by thoroughly mixing a fine abrasive in the glass batch while it is in its molten state and afterward moulding and grinding in practically the same manner as for plate glass. The result is a fine velvety surface that takes chalk well, can be easily cleaned, and will not wear smooth or discolor. These boards can also be had in a variety of colors.

Tempered Glass.—Another important development in the industry is the production of so called "tempered" glass. In general this is produced by heating plate glass to a plastic condition and then suddenly air cooling it. The product is very much stronger than ordinary glass. It can be bent and twisted without breaking and is not affected by sudden change of temperature. If it is broken under severe stress, it crumbles into small pieces without sharp edges. It cannot be cut when cold like ordinary glass.

One of the outstanding achievements in the glass industry in recent years is the production of commercial spun glass. Less than one-tenth the size of the human hair but with tensile strength of mild steel, it has already found use in a variety of commodities. It can be woven into textiles for clothing, upholstery, and other purposes; it will not stretch or shrink, is fire- and verminproof, will not fade, corrode, or decay, and can be produced in a large variety of beautiful colors. It is especially adapted for insulating material and can be either applied in new building construction or blown into the walls of old structures. Its special features in this respect are its durability, its non-conduction of heat and cold, its proof against fire and vermin, and the ease with which it can be applied.

Another important recent development in the glass industry is the production of glass building blocks, which are coming into use for outside walls for office and other higher class buildings as well as for interior work for partitions, ceilings, etc. The blocks are constructed of clear, colorless glass that transmits a maximum amount of light of daylight quality, in a variety of sizes, shapes, and designs to meet architectural and other requirements. As a rule the blocks are made up hollow, of two halves fused together into one strong unit. Their special advantages are not only excellent light-transmission and sanitary qualities but also power to insulate against heat and cold and to deaden street and other noises. Glass-block walls are laid up in special mortar in a manner similar to that used in laying up bricks.

Glass Terms

bait—A straight iron bar lowered horizontally into a tank of molten glass to which a web of glass clings and is lifted and started in making common flat window glass.

batch—The combination of raw materials for making glass.

bridge—A refractory bar, or member, of fire clay placed across the surface of the batch in a tank furnace near the working end to hold back the scum, or gall.

casting plate (also **casting table**)—A flat iron table upon which molten glass is poured to flatten out.

closed pots—Fire-clay pots for melting glass with the top nearly closed to keep out the products of combustion and other impurities.

cullet—Old broken or waste glass used in new batches.

cut glass—Fine quality of glass articles produced by forming and afterward decorating with designs by grinding and polishing on special wheels.

dog house—The opening in the end of the tank furnace for charging.

electrocast—A term applied to a refractory brick or block produced by melting the raw materials in an electric furnace and casting into a mould.

fining—Keeping glass in a fluid state until all the gases have escaped.

flattening furnace—A special furnace for reheating glass cylinders that are blown for window panes so that they can be flattened out.

floaters—Fire-clay blocks floating in the batch of a tank furnace to keep the gall out of the working end (for the same purpose as the bridge).

gall—The scum or impurities that rise to the top of the molten glass.

grog—Pieces of old pots broken down and ground up for use with new clay for new pots.

iridescent glass—Glass having a variety of colors.

lead glass—Glass having lead as one of its principal ingredients; generally high-grade glass.

lehr—An annealing furnace used for cooling glass slowly.

lime glass—Glass having lime as one of its principal ingredients.

milk glass—White glass made by the addition of fluorspar, tin, or some other special mineral.

open pots—Fire-clay pots for melting glass—open at the top.

plate glass—Thick glass produced by casting, grinding down, and polishing.

pot furnace—A glass furnace in which the batch is melted in pots.

pressed glass—Glass articles produced by pressing plastic glass into moulds.

pyrex—A borosilicate glass with low coefficient of expansion and high-temperature resisting qualities.

salt cake—Crude sodium sulphate, used for glass batches.

soda ash—Crude sodium carbonate obtained by heating ordinary washing soda to drive off the water.

soda-lime glass—Common glass from a batch of sand, lime, and soda ash.

striae—Small, irregular, wavy lines or streaks in glass which deflect waves of light and make objects appear distorted.

tank furnace—A glass furnace in which the batch is melted in a large tank.

translucent glass—Glass that will admit rays of light to pass but through which objects cannot be seen.

transparent glass—Glass through which objects can be seen.

tuiles—The working openings at the discharging end of a glass furnace.

wire glass—Glass reinforced by wire mesh embedded in the molten mass when it is cast.

Glass Questions

Group I

1. What nation is reported to have discovered glass?

2. What evidences have we that glass was known in very early times?

3. What Roman writer mentions glass? About what time was this?

4. How was manual labor looked upon in medieval times? How did this affect all industry?

5. What notable court decree was made in connection with glass making in early times? Explain why this was done.

6. Name some of the glass articles that seem to have been the first used.

7. Where was the first glass factory in this country supposed to have been located?

8. Why did the glass industry in this country develop very slowly?

9. Name some reasons for the rapid development of the glass industry in this country in the past few years.

10. What countries furnished practically all optical glass before the World War?

11. Give the names of the general materials used in the three main types of glass batches respectively.

12. About what size and shape are the largest tank glass furnaces? How are common glass milk bottles formed?

13. Why is lead glass especially good for fine cut-glass ware?

14. Explain how plate glass is ground and polished.

15. Why is wire sometimes embedded in glass? Explain how this is done.

16. How are bent or curved plate-glass sheets produced?

17. How is non-shatterable glass produced?

18. How were flat glass articles made in ancient times?

Group II

19. Why must glass be annealed?

20. Why was the glass industry among the first to be started in this country?

21. Why is glass especially good for laboratory equipment?

22. Mention two general types of glass furnaces and give advantages of each.

23. Mention articles made from glass for which the batch can be more or less impure.

24. Why do objects seen through common window glass sometimes seem distorted?

25. What are some of the problems to be considered in selecting material for glass-melting pots?

26. What are some of the factors that would determine the size of a tank glass furnace?

27. What makes common glass shatter when subjected suddenly to heat?

28. What is the use of the lehr? What determines its length?

29. What are some of the requirements for optical glass? Why are melting pots for optical glass used but once?

30. What factors would be likely to determine the location of a glass factory in a section?

31. Why is shatter-proof glass especially good for wind shields?

32. Why should gas be especially desirable for fuel for a glass furnace?

33. Explain why optical glass is harder to produce than other high-grade glass?

34. What is meant by the center of the glass industry?

35. Why is glass especially useful in electrical work?

COAL

Formation and Nature of Coal.—Coal is the fossilized remains of vegetable matter that has lain embedded in the rocks for untold ages. The weight of the overlying materials has distilled out all organic matter and obliterated practically all trace of vegetable structure, leaving only the compact black mass of coal behind.

Workable beds of coal are found in rocks of all ages, indicating that the coal-forming process has been continuous. Indeed, it is still going on in the jungles

of the lower Amazon Valley, the Dismal Swamp of Virginia, and in other places where vegetation is sinking and being covered with clay and sand. It is to be noted, however, that the vegetation which formed our present coal supply was quite different from that on the earth today.

There is a wide variation in the number and thickness of anthracite veins throughout the region in the state of Pennsylvania, with a varying amount of rock formation between. These veins were laid down during separate periods of tropical growth such as the world has never since experienced. A period of carboniferous growth was covered by slime, mud, and sand, and then the tropical growth was resumed producing material for alternating thicknesses of coal and rock. Tremendous pressure and heat compressed and baked the vegetable matter into coal and the mud into rock. Anthracite coal at one time was the same as bituminous coal is today, but pressure and heat increased carbonization and drove off many of the volatile elements that bituminous still contains.

The use of coal as a general fuel is of comparatively recent date.

Historical Sketch.—Records show that its use for smithing, which is its earliest recorded use, dates back only as far as 300 B. C. Pliny mentions it in about 50 A. D. It was known and used in Great Britain during the Roman occupation, and from that period on it has been used more or less commonly in that country. It is reported that coal gas was used for public lighting at the celebration in London in 1815 of the victory of Waterloo.

In the United States the use of coal was limited up to about the middle of the last century. At first, the American people were skeptical about attempting to use it and looked upon it with suspicion. It is reported that on one occasion certain parties were obliged to flee from Philadelphia by night to escape being arrested for attempting to sell "black stones"

FIG. 150.—Early method of ventilating coal mine. *a.* Mine entrance. *b.* Bellows. *c.* Air pipe. (*Courtesy of Standard Oil Company of New York.*)

for fuel. On another occasion some workmen after trying all night to start a coal fire in a blast furnace without success became disgusted, slammed the door, and went to breakfast. When they returned, the fire was at white heat. All it needed was to be left alone long enough to ignite and get under way.

Gradually, however, as stoves and furnaces were developed for the better burning of coal, its merits became known, and its use rapidly increased, until at the end of the past century it was practically the uni-

versal fuel for generating steam and domestic heating. But as coal took the place of wood, so petroleum and hydroelectric power are gradually taking the place of coal, especially for railroads and other industrial uses and also for domestic heating. The time is far distant, however, when coal will no longer be needed in certain branches of metallurgy and for heating and power purposes in sections where oil and facilities for generating electricity by water power are not available.

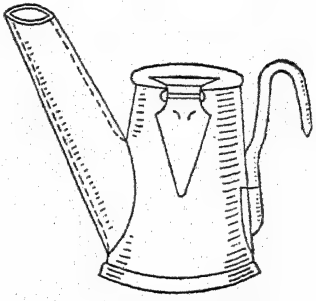

Fig. 151.—Miner's oil lamp.

Kinds of Coal.—There are three general kinds of coal in use: anthracite, bituminous, and lignite. To these might be added peat, although peat can hardly be classified as coal. Rather it is vegetation in the first stages of transition in the coal-forming process. Between the main divisions there are many intermediate varieties of coal ranging from soft lignite to the hardest anthracite, as hard, soft, coking, non-coking, high sulphur, low sulphur, high phosphorus, and low phosphorus according to its nature and the amount of impurities that it contains. The United States has all of these varieties in large quantities.

Carbon is the principal heating element. Consequently the variety having the highest percentage of carbon is the most valuable for heating. Anthracite leads others in this respect, sometimes having a carbon content of more than 85 per cent. It is also prac-

tically free from smoke and other volatile matter, which makes it especially valuable for domestic heating. Common commercial sizes of anthracite are egg, stove, nut, pea, buckwheat, and barley.

Coal Deposits.—Practically the only anthracite beds in the United States are found in northeastern Pennsylvania in an area comprising about 485 square miles. Small seams of anthracite are found in Rhode Island, Colorado, and New Mexico, but the quantities in these states are too small to be of commercial importance, and the quality inferior to that of Pennsylvania. Practically all the anthracite used in the United States for the past sixty years, as well as considerable quantities for export trade, has been mined from the beds of Pennsylvania. The supply is beginning to show signs of exhaustion in certain sections, and a considerable percentage of anthracite mining at the present time consists in removing pillars left for roof supports in former operations. To offset this, however, geological survey estimates set our original anthracite at 20,000,000,000 tons, of which less than 5,000,000,000 tons have been mined.

Our supply of bituminous coal is ample for many years to come, provided we are reasonably conservative in its use. It contains a much larger percentage of volatile matter than anthracite; hence, it is better for the production of illuminating gas, coke, coal-tar products, etc., and less desirable for domestic heating. It is softer than anthracite, ignites more easily, and burns with a larger flame, making it especially good for firing boilers and kilns and for general metal-

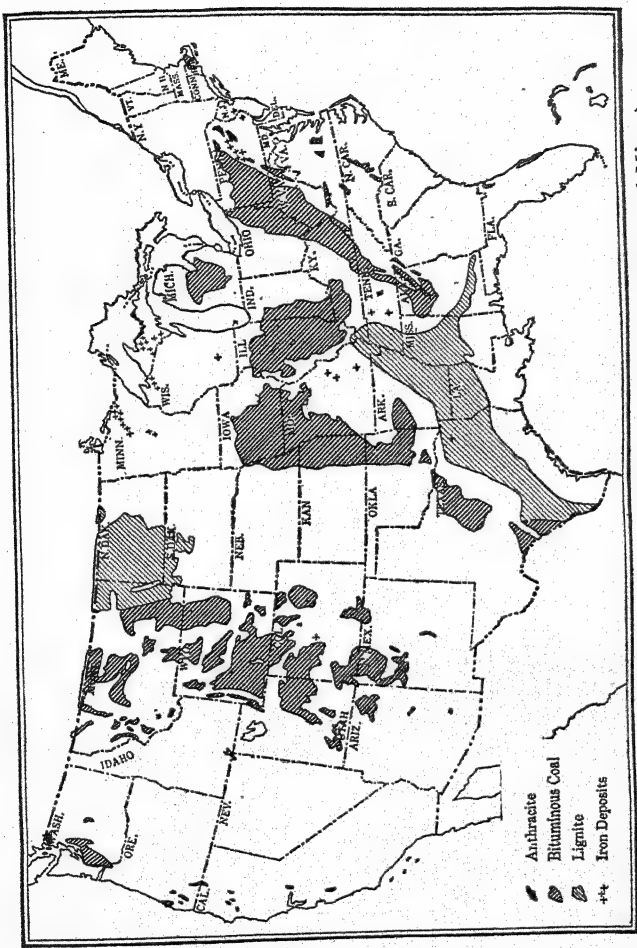

FIG. 152.—Coalfields of the United States. (*Courtesy of Bureau of Mines.*)

lurgical work. At the present time, bituminous coal is mined in thirty states, the leading ones being Pennsylvania, West Virginia, Illinois, Ohio, Kentucky, Indiana, and Alabama (Fig. 152).

Lignite is a soft brown coal which deteriorates rapidly when exposed to the air. For this reason it cannot be stored for any length of time or transported great distances without losing some of its heating qualities. The principal lignite deposits in the United States are in North Dakota, eastern Montana, Texas, and Louisiana (Fig. 152). At the present time it is mined and used locally to a considerable extent. Its content of gas and other volatile matter, however, renders it a valuable supply for these products against the time when they can no longer be obtained in sufficient quantities from bituminous coal and other sources.

Asia has vast reserves of coal, especially in China and Siberia, where it is estimated that 80 per cent of the world's supply of anthracite lies buried. Comparatively little mining has been done in these countries, and little is known of the nature and extent of the deposits.

Europe has coal mines in nearly all her countries. But much of the coal in the central section is of low-rank bituminous and lignite. The leading producing sections rank as follows: England, Germany, Austria, Poland, France, Belgium, and Russia.

South America has relatively small coal reserves, but owing to her tropical climate and scarcity of coal-using industries her consumption is very small com-

pared to that of North America. About 80 per cent of her production comes from Chile, with Peru, Colombia, Venezuela, and Brazil following with small quantities.

Africa apparently has larger reserves of coal than South America, but her mines are not worked on an extensive scale. Her principal deposits are in the Union of South Africa and Rhodesia. The supply meets the local demands and furnishes considerable quantities for bunker trade. Australia and New Zealand have ample deposits of coal for domestic use for generations to come. It is also found more or less extensively in the East Indies, Canary Islands, Philippines, and Japan.

Coal is widely distributed over the whole earth, and nearly every country has at least a small supply. The United States leads in production, with England coming second and Germany third. The Appalachian and interior fields of the United States supply not only the great bulk of all the coal used on the American continent but also over 35 per cent of that consumed in the world.

Compared to its weight, coal is a cheap commodity; consequently the expense of transportation enters largely into its cost to the consumer. Great Britain has been able to dominate the coal trade of the Mediterranean countries for many years because of her cheap method of transportation. Coal from her mines near the sea can be loaded on shipboard and transported to Mediterranean ports at a very low rate in view of the fact that it can serve as ballast on

outgoing ships that are used for import trade. This same practice is resorted to in connection with the transportation of iron ore on our Great Lakes. Boats bringing iron ore from the Northwest carry back

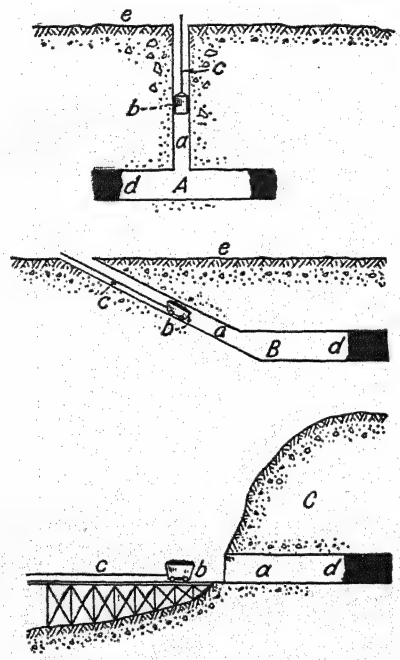

FIG. 153.—Types of coal mines. *A*. Shaft mine. *B*. Inclined plane or slope. *C*. Drift mine. *a*. Main opening. *b*. Car or cage. *c*. Traction or hoisting cable. *d*. Face, breast, or heading. *e*. Surface.

coal at a much lower rate than it can be carried by railroad.

Coal veins differ widely in their character and position. Some of them are practically level, while others tilt to steep inclines and even fold. Some lie buried deep in the earth, while others crop out on

the hillsides, and even in the lowlands. Some are only a few inches thick, while others run as high as sixty feet or more. As a rule, the deeper the vein the harder the coal and the less volatile matter it contains.

Mining.—There are three general methods of reaching the coal in mines: the shaft; the slope, or incline plane; and the drift, or open pit (Fig. 153). In the first method at least two shafts must be sunk, one for hoisting the coal, transporting the miners' supplies, etc., and the other for a passageway for the escape of foul gases or the admission of fresh air. In the second method a tunnel is bored from the surface on an incline or slope. In the third method the drift, or outcrop, is reached by tunneling or by stripping and using open-pit methods of mining.

The method employed depends upon the nature of the country, the thickness of the vein, and the nearness of the coal to the surface. When surface indications show that coal underlies a section, a test hole is drilled, generally with a hollow drill that brings up samples of the materials encountered. If a vein of coal is struck of sufficient thickness to pay for working, shafts are sunk, and other preparations are made for mining. One of the first considerations is proper ventilation, which requires the knowledge and skill of the best mining engineers. At least one fan must be installed at every mine to force a circulation of fresh air (Fig. 154). This is generally located at the mouth, or opening, of a special shaft and either draws the foul gases out or forces the fresh air in. Sometimes these fans must have a rim speed of a

mile a minute to create sufficient draught to keep the mines properly ventilated. A complete system of air passages, ducts, splits, gates, etc., must be installed and advanced as fast as the mining progresses. (Any neglect on these points will sooner or later result in disaster.) Pumps must be installed and kept running to free the mine from water, barns provided to care for the mules, electric lights installed, tracks laid for transporting the coal, and many other preparations

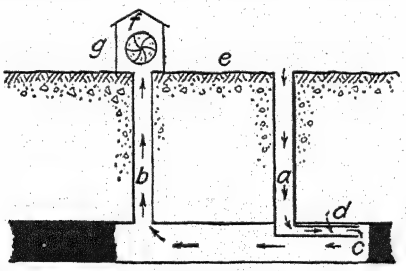

FIG. 154.—Mine ventilation. *a*. Main shaft. *b*. Air shaft. *c*. Face. *d*. Air duct. *e*. Surface level. *f*. Fan. *g*. Fan house.

made so that mining can be carried on safely and efficiently.

Formerly, all mining was done by hand, and the work was among the most arduous to be found. Often the miners were obliged to lie on their sides or take other uncomfortable positions in digging the coal loose. In foreign countries even women and children were compelled to drag the heavy cars of coal to the surface, but in recent years special mining machinery has largely taken the place of hand labor. Electric and air drills have displaced old hand drills; cutting machines have taken the place of hand picks and drills; loading machines are displacing the hand shovels;

electric locomotives haul cars once drawn by hand or by mules; and electricity illuminates the dark recesses in place of the oil lamp. Even the romantic teapot-like lamp of the miner's cap (Fig. 151) has given way to a special electric headlight connected with a battery strapped to the back.

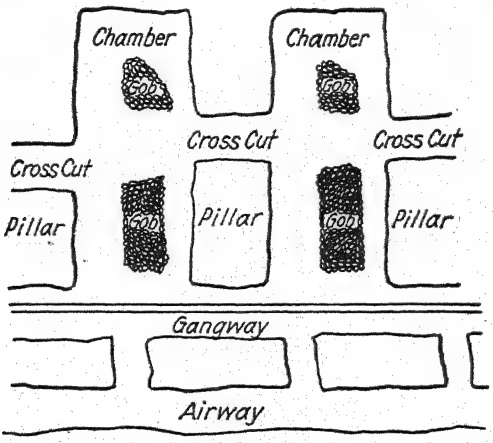

FIG. 155.—Room-and-pillar method of coal mining, leaving pillars.

There are two general methods in the actual mining, namely, the room-and-pillar method and the long-wall method (Figs. 155 and 156). In the room-and-pillar method, rooms are worked out adjacent to a central gallery, and pillars left at intervals to support the roof. Afterward the pillars are removed, and the roof allowed to fall. In the long-wall method, the face, or breast, is worked out in a long, irregular curve without leaving pillars (Figs. 157, 158). As a rule, a larger percentage of coal can be secured by the long-wall method, but it can be employed only where the

rocks of the roof are of such a nature as to hold up for large spaces without aid of intermediate supports.

Coal is loosened from the beds by blasting, either by simple drilling or by use of the undercut. If simple

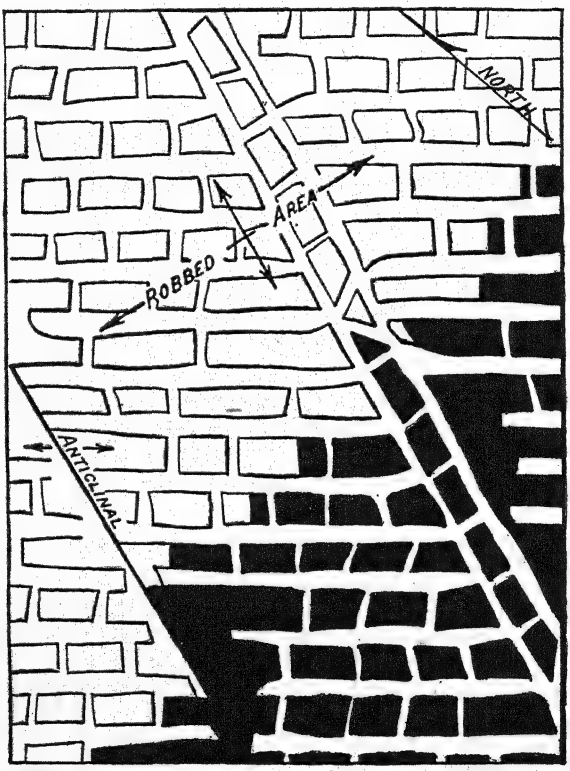

FIG. 156.—Room-and-pillar method of coal mining, robbing pillars.

blasting is used, holes four or five feet deep are drilled in the breast, and the coal is blasted out (generally with special blasting powder). When the undercut method is employed, a channel four or five feet deep and several feet long is cut at the bottom of the seam,

and the coal is wedged or blasted down from above (Fig. 159). The undercut method is more profitable not only because it is cheaper but also because the coal is not broken up into small pieces, but it can be used only where the vein is practically level.

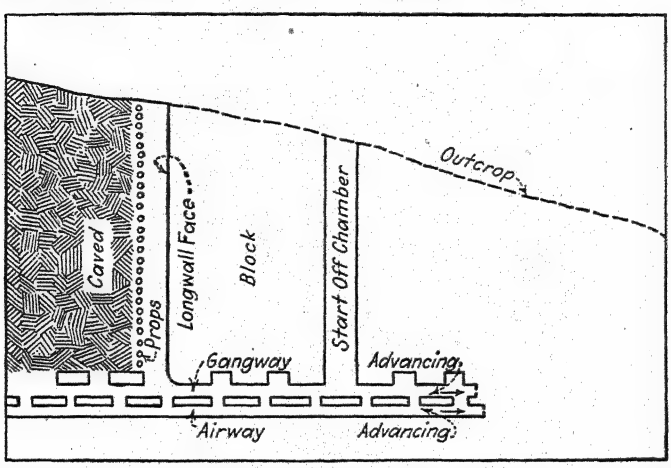

FIG. 157.—Long-wall method of coal mining (advancing long wall). (*Courtesy of The Hudson Coal Company.*)

Cleaning and Grading Coal.—As soon as the coal is blasted loose, it is loaded into cars either by hand or by machines (Fig. 160) and is hauled away to the foot of the shafts or slopes to be taken to the surface. If it is bituminous coal, it is practically ready for the market as soon as it leaves the mine. But anthracite must first go through a cleaning and grading process before it is ready for market. The cleaning and grading are done in what is known as the "coal breaker." This consists of a huge, irregular building equipped with crushers, screens, slate pickers, and other apparatus.

The coal is first hauled to the top of the breaker and sent through a crusher to break it up (Figs. 161,

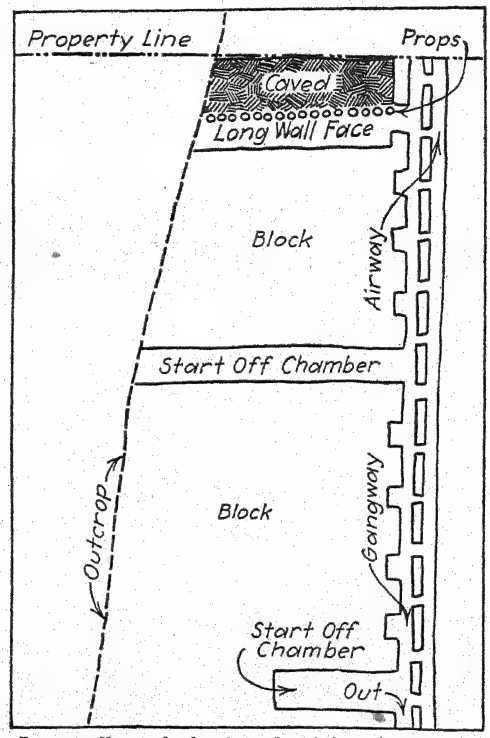

FIG. 158.—Long-wall method of coal mining (retreating long wall). (*Courtesy of The Hudson Coal Company.*)

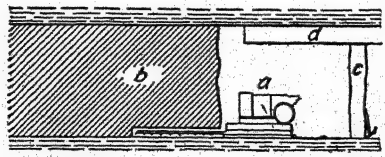

FIG. 159.—Coal mining with undercutting machine. *a.* Machine. *b.* Coal. *c.* Mine prop. *d.* Roof timber.

162). It then travels by gravity over screens of different mesh which separate it into sizes. From here

it goes to the slate-picking process, where the slate is removed, and finally through the chutes to the storage bins ready for shipment. Formerly, the slate

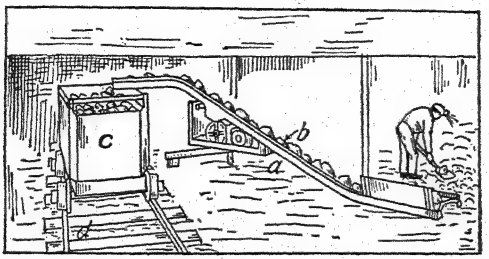

FIG. 160.—Coal loader. *a*. Motor. *b*. Conveyor. *c*. Coal car. *d*. Track.

was removed entirely by hand by slate-picker boys who sat or stood by the chutes and picked out the pieces of slate as the column moved along, but in

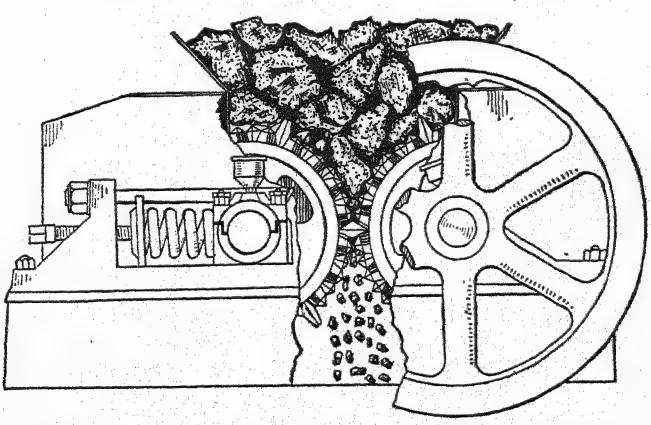

FIG. 161.—Coal crusher. (*Courtesy of Link Belt Company.*)

recent years special slate-picking machines have been invented which have largely taken the place of hand labor. Several types of these machines are on the

market, among the most common of which is the so-called "jig" type (Fig. 163). In this machine the coal and slate are pulsated up and down in a tank of water, and the coal, being lighter than the slate, is forced to the top by the water while the heavier slate sinks and is removed from the bottom. Nearly all processes in the breaker are carried on with water on the coal. This practice does away with the dust,

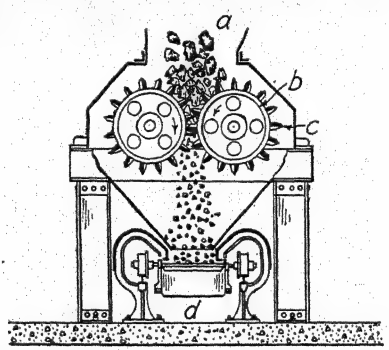

FIG. 162.—Coal crusher. *a*. Coal. *b*. Cylinders. *c*. Cylinder teeth. *d*. Car. (*Courtesy of Link Belt Company.*)

which is not only injurious to the workmen but also often a nuisance to the surrounding neighborhood.

Another mechanical slate picker sometimes used for larger sizes of coal utilizes the principle of centrifugal force. The apparatus generally consists of a spiral chute constructed around a vertical shaft (Fig. 165). The coal is fed into the chute at the top and is made to travel downward by gravity. As the momentum increases, the pieces of slate, being heavier than the coal, are thrown farther out by the centrifugal force and pass over the edge of the chute leaving the coal to pass on down to the bottom.

A modern and effective method of cleaning anthracite coal is the so-called "cone-cleaning" process. The apparatus consists, in the main, of a large upright cone filled with a mixture of sand and water agitated by revolving paddles on a central shaft (Fig. 164).

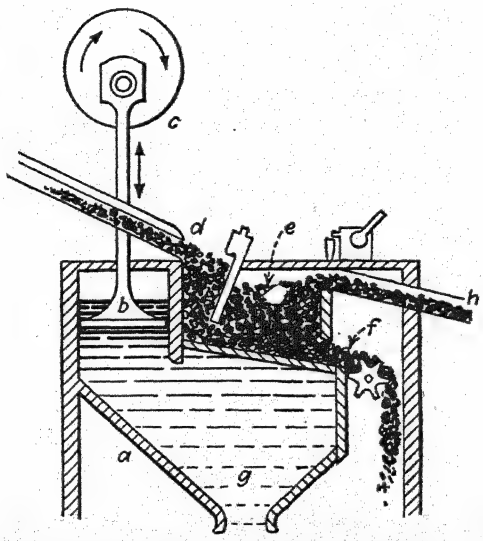

FIG. 163.—Jig-type slate picker. *a*. Tank. *b*. Plunger. *c*. Eccentric. *d*. Coal chute. *e*. Uncleaned coal. *f*. Slate. *g*. Water. *h*. Cleaned coal. (*Courtesy of Lehigh Navigation Coal Company.*)

The run-of-mine coal enters the top of the cone through a chute, and the density of the mixture floats the coal but allows the slate to sink and pass out at the bottom.

Coal is generally mined by the ton. The miner contracts to produce and load a given number of cars or tons per day. He generally furnishes his own supplies and hand tools and hires his own helper. If he is successful with his blasts he may finish his day's

work in a few hours, but if not he must stay until his quota of tons is mined.

Safety First.—The law provides that every precaution must be taken to insure the safety of the miners, and a careful check-up of all parts of the mines is constantly made. Every man has his individual

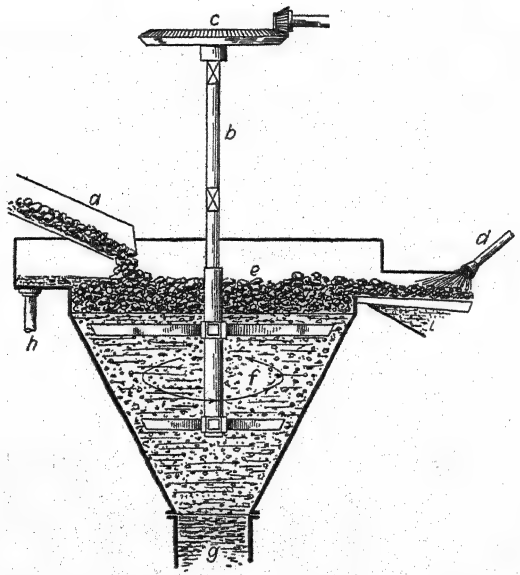

FIG. 164.—Cone slate picker. *a.* Coal feed. *b.* Agitator shaft. *c.* Bevel gear. *d.* Clean-water spray. *e.* Coal. *f.* Sand and water. *g.* Slate. *h.* Sand-and-water return. *i.* Sand and water. (*Courtesy of The Hudson Coal Company.*)

number, which is recorded and hung on a chart at the entrance of the mine opposite the number of the room in which he is working, so that his exact location can be determined at all times. During the night all sections of the mines where the miners work are inspected for dangerous gases under the direction of

an expert fire boss; and the miners are warned the next day before they enter if dangerous places are discovered. In spite of all precautions, however, we too frequently have mine disasters, showing that the systems of operation have not yet been perfected or that individuals responsible for the safety of the miners have failed in their duties.

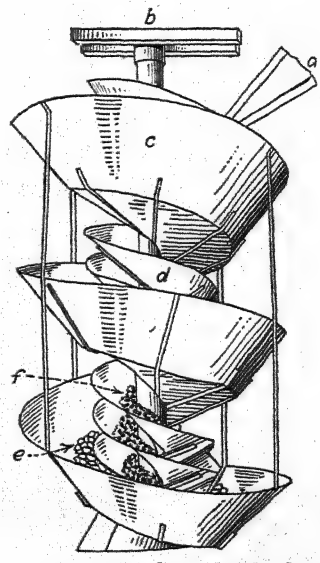

FIG. 165.—Centrifugal slate picker. *a*. Feed. *b*. Shaft. *c*. Outer spiral chute. *d*. Inner spiral chute. *e*. Slate. *f*. Coal. (*Courtesy of Bureau of Mines.*)

Recovered Coal.—For many years thousands of tons of good anthracite coal were thrown out on the culm dumps as not worth saving. At one time the problem of finding space for this seemingly worthless material was difficult and expensive, especially around the cities. But in recent years advanced prices of coal and improved methods of burning small sizes in the industries have made it profitable to work this culm over. So thoroughly has this been done in most places that only small amounts of worthless rock and slate and other useless materials remain in places where mountains of this culm formerly stood. Profitable reclamation work has also been carried on by dredging river bottoms, where finer sizes of coal have been washed downstream in floods. This is especially

important in the Susquehanna River below Wilkes-Barre, where thousands of tons of perfectly good coal have been recovered.

General Use of Coal.—The general uses of coal in the United States are as follows: (1) generating steam; (2) heating; (3) manufacturing coke; (4) manufacturing illuminating gas; (5) firing lime, cement, and brick kilns; (6) manufacturing producer gas; (7) smithing. Someone has said that coal is the base of the pyramid upon which all mineralogical and almost all other human industries are built. It moves thousands of mighty ships through the seas; sends a hundred thousand locomotives spinning over the iron ways of the world; melts millions of tons of iron ore from which we fashion all our machinery and countless other appurtenances of modern civilization; makes busy factories hum in towns unnumbered; lights our streets; heats our homes; colors our clothing; and furnishes the sweet for drugs and some of our food; in fact, whichever way we turn, manufactured objects meet our eye, and luxuries are enjoyed that are directly or indirectly dependent upon coal.

Coal Terms

afterdamp (choke damp)—The deadly gas occuring in a mine after an explosion or a blast.

anthracite—Hard coal, high-carbon coal.

barley coal—Fine size of anthracite coal about the size of barley grains.

bituminous coal—Soft coal. Coal containing a large amount of volatile matter.

bone—Pieces containing alternate thin layers of coal and slate.

breaker—The large building at a mine for breaking, screening, and cleaning coal ready for market.

breast (**heading**)—The face of a mine where the coal is dug out.

briquettes—Coal screenings mixed with tar or some other bonding materials and pressed into lumps.

buckwheat coal—Fine anthracite about the size of buckwheat grains.

cage—The car opeating in the shaft to hoist the coal and transport the miners and supplies.

chaf—A piece of coal or ore with rock adhering to it.

crusher (also **cracker**)—The revolving cylinder which breaks up the coal after it comes from the mines.

culm—The dust, slate, and other dirt that have been removed from the coal.

drift—An outcropping, or open-pit, mine.

duct—A pipe or air passage for ventilation in a mine.

egg coal—Anthracite coal about the size of a large egg, generally used for domestic heating.

face—Same as breast.

hoist—The apparatus for hoisting coal up a shaft out of a mine.

incline plane (also **slope**)—A slanting opening into a mine.

lignite—Soft, brown, bituminous coal.

mine props—Sections of wood generally of small tree trunks, used for holding up pieces of rock in the roof of mines.

pea coal—A small size of domestic anthracite.

peat—Partially carbonized vegetable matter, generally from moss.

rice coal—The smallest size of anthracite coal for commercial use.

run-of-mine coal—Coal as it comes from the mine before it has been cleaned.

seam (also **vein**)—A layer of coal in the rocks.

semi-anthracite—Anthracite coal with a high percentage of volatile matter.

sprag—A piece of hardwood about two feet long and pointed at both ends, used for chocking the wheels of a mine car to act as a brake.

stove coal—The common domestic size of anthracite.

subbituminous coal—Bituminous coal approaching lignite.

undercut—A channel at the bottom of a vein of coal cut for the purpose of enabling the miners to break down more at one blast.

Coal Questions

Group I

1. From what is coal supposed to be derived?

2. What evidence have we that coal was derived from vegetation?

3. Name the three principal varieties of coal.

4. Where are the anthracite beds of the United States? How extensive are they?

5. Name the leading bituminous-coal-producing states.

6. How are coal mines classified? Why must there always be two shafts, or openings, to a mine?

7. What element in coal makes it especially good for fuel?

8. Name and explain two general methods of coal mining.

9. What is meant by culm? How is culm utilized at the present time?

10. What is meant by volatile matter in coal?

11. What is meant by lignite? What happens to lignite if it is exposed to the air for any length of time?

12. Name the principal lignite-producing states.

13. Explain the action of the cone type of slate picker.

14. What causes coal to float in the jig-type slate picker?

15. What is meant by a mining crew?

Group II

16. What serious problem did culm formerly present in larger cities?

17. What is meant by peat? What relation does it have to coal?

18. Explain two ways in which a fan may work to ventilate a mine.

19. What are some of the dangers met with in mining coal?

20. Mention some of the things that science has done in recent years to lessen the danger in coal mining.

21. How is electricity applied to coal mining?

22. Explain what is meant by a coal breaker, and give the main reason for constructing them so high.

23. What is the advantage of the practice of undercutting in coal mining? Explain your answer.

24. Why may we expect to find coal widely distributed in the world?

25. What causes coal to float in the cone-type slate picker?

26. Compare the principle involved in the jig-type slate picker with that of the cone slate picker.

27. By what characteristics do we recognize a good grade of anthracite?

28. What is meant by wash coal? Why is it always of small size?

29. What is meant by river coal?

30. Mention one location where considerable quantities of river coal are found.

31. Why is river coal always of small sizes?

COKE

General Need for Coke.—A large percentage of the bituminous coal mined is manufactured into coke for the smelting of iron ore and for other branches of metallurgical work. At one time, charcoal was practically the only fuel used for these purposes, but because of its fragile nature and its scarcity and increasing cost it became necessary to find other fuel. Raw bituminous coal was not satisfactory for iron smelting because of its tendency to become plastic at lower temperatures and its high percentage of impurities. Anthracite was not suitable because it is too dense for rapid burning, has too high an ash

content, and often breaks up into fine pieces in the furnace when it becomes hot, causing it to pack down. The problem was finally solved by the adoption of coke, a nearly pure carbon product, obtained by heating or baking certain grades of bituminous coal (coking coal) in the absence of air.

Principle and Processes of Manufacture.—The development of the coke industry in this country was

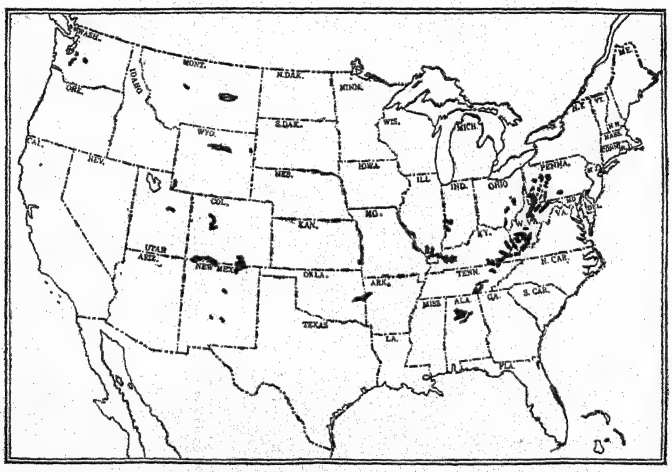

FIG. 166.—The principal coking-coal deposits of the United States. (*Courtesy of Bureau of Mines.*)

incidental to that of iron and steel. The modern blast and cupola furnaces require for reduction and melting of their respective charges a solid fuel reasonably cheap, high in carbon content, low in ash, rapid burning (and hence porous in structure), and strong enough to withstand the burden of the charge without disintegrating into fine particles. Coke is the fuel that meets all these conditions in the most satisfactory manner.

When bituminous coal is heated to a high temperature (about 1800°F.) in a closed chamber out of contact with air, it undergoes a process of decomposition known as "carbonization." During the process the heat drives practically all the volatile matter (gas, tar, ammonia water, and oils) from the coal. The solid residue, or char, which remains is called "coke." In appearance coke is a grayish, porous, brittle, irregularly shaped solid. It is higher in carbon and ash content than the original coal and has a specific gravity slightly less than water.

There are three general processes for making coke: (1) the beehive process, (2) the by-product process, and (3) the gas-house process.

Beehive Process.—Beehive coke was the first coke of importance to be used in this country. A typical beehive coke oven consists of a domelike chamber about 12 feet in diameter at the bottom and 7 feet high in the center, inside measure, fashioned somewhat after an old-time straw beehive, from which it takes its name (Fig. 167). The inside is lined with fire brick and covered with clay or earth to retain the heat. The floor is flat and slightly inclined to facilitate discharging, and a low arched door is constructed at the bottom at the edge of the chamber for quenching and drawing the coke. In the center of the top is a round hole called the "trunnel head," or "eye," through which the charge is introduced and the gases escape to the atmosphere.

There are three general systems of these ovens in use according to their arrangement, namely, the bank system, in which the ovens are built in a single row

against a bank; the single-block system, in which there is a single row supported on either side by a retaining wall; and the double-block system, in which there are two rows of ovens placed back to back or staggered. The whole structure is held in position by rough masonwork retaining walls.

Before the oven is started, the drawing door is bricked up except for a narrow crack at the top to

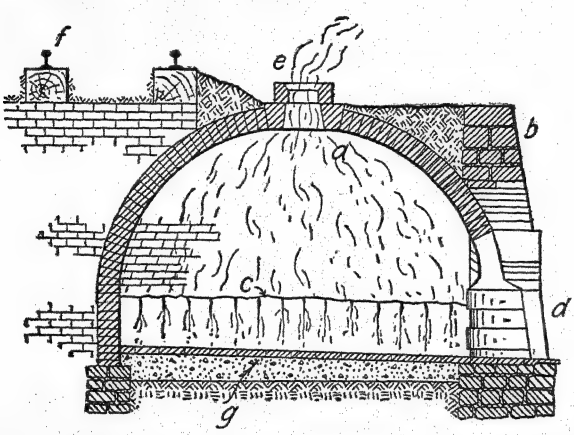

FIG. 167.—Beehive coke oven. *a*. Arched roof. *b*. Retaining wall. *c*. Charge. *d*. Drawing door. *e*. Trunnel head, or eye. *f*. Tracks. *g*. Slanting floor. (*Courtesy of Bureau of Mines.*)

admit enough air to keep the volatile matter burning. A wood and coal fire is then built on the floor and allowed to burn until the interior has reached a temperature sufficiently high to start the coking process. The charge of coal is now introduced, and the coking proceeds because of the heat generated in the burning of the gases that escape from the coal. Depending upon the time allowed for coking and the results desired, the weight of the charge varies from

six and a half to eight tons of coal. The higher the grade of coke desired the larger will be the charge and the longer the time for coking. As soon as the coking process is finished, the coke is partially quenched through the drawing door with a hose by hand or with an automatic sprinkling device, which causes it to break into large fragments. The coke is now drawn and further cooled by quenching, and a new charge of

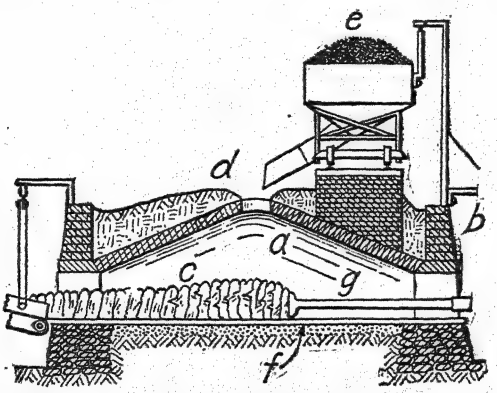

FIG. 168.—Mitchell or longitudinal coke oven. *a*. Arched roof. *b*. Retaining wall. *c*. Coke. *d*. Trunnel head. *e*. Coking coal. *f*. Floor. *g*. Discharging ram. (*Courtesy of Bureau of Mines.*)

coal is introduced while the oven is still hot enough to start the next batch coking. The product is graded according to the time allowed for coking, as seventy-two-, forty-eight-, and twenty-four-hour coke.

The beehive coke oven has been superseded by the by-products oven and is practically obsolete.

Mitchell Coke Oven.—Early in the present century there appeared in this country a modified form of a Belgian longitudinal coke oven known as the "Mitchell oven" (Fig. 168). The essential features of this oven

are a long rectangular chamber with a flat bottom, an arched roof, a trunnel head in the center of the top, and a door at either end. The operation of the oven was practically the same as the beehive oven except that the coke was pushed out with a mechanical pusher instead of being drawn. These ovens were

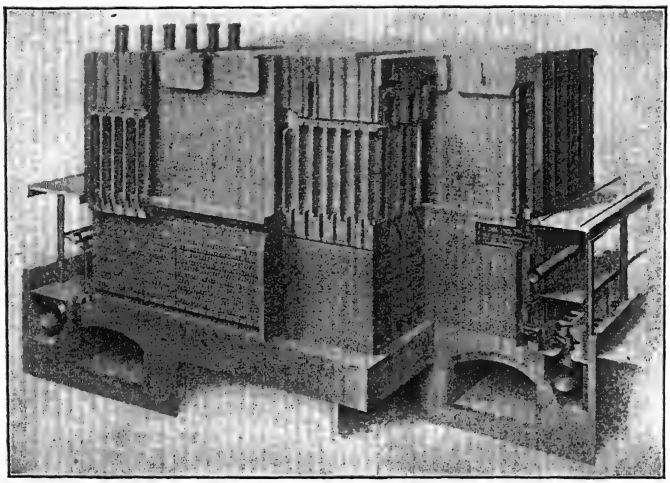

FIG. 169.—Modern by-products coke oven. (*Courtesy of Koppers Construction Company.*)

never used to any great extent in the United States, largely because of the well-established beehive practice and more recently because of the cheapness and ease with which excellent metallurgical coke can be produced in the modern by-product ovens.

By-product Process.—At the present time the great bulk of all metallurgical coke is produced with the by-product process, largely because of the economic saving of the gaseous vapors which are generally lost

in the beehive process and from which valuable by-products are obtained. The construction of a by-product coke oven is much more elaborate than that of a beehive oven. A typical unit by-product oven consists of a rectangular retort or chamber from 30 to 40 feet long, 6 to 15 feet high, and 12 to 22 inches wide, inside measure (Fig. 169). The inside walls are built of silica brick, and the outside walls and top of

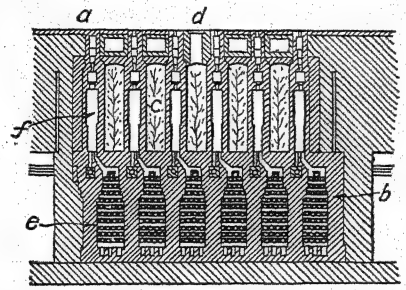

FIG. 170.—Earlier type of by-products coke oven. *a*. General structure. *b*. Refractory lining for regenerative chambers. *c*. Unit oven or retort. *d*. Trunnel for charging. *e*. Regenerative chamber, checkerwork. *f*. Combustion chamber.

fire brick. The ends are closed by refractory-lined doors which are removed when the coke is discharged. From ten to ninety of these ovens are placed side by side in a row constituting a battery. Sandwiched between and adjacent to the ovens are combustion flues or chambers in which part of the coal gas is burned to heat the ovens for coking. Considerable heat economy is accomplished by means of a regenerative system of a checkerwork porous fire brick underneath the ovens for preheating the air and fuel gases (Fig. 170). In the top of each oven are openings for

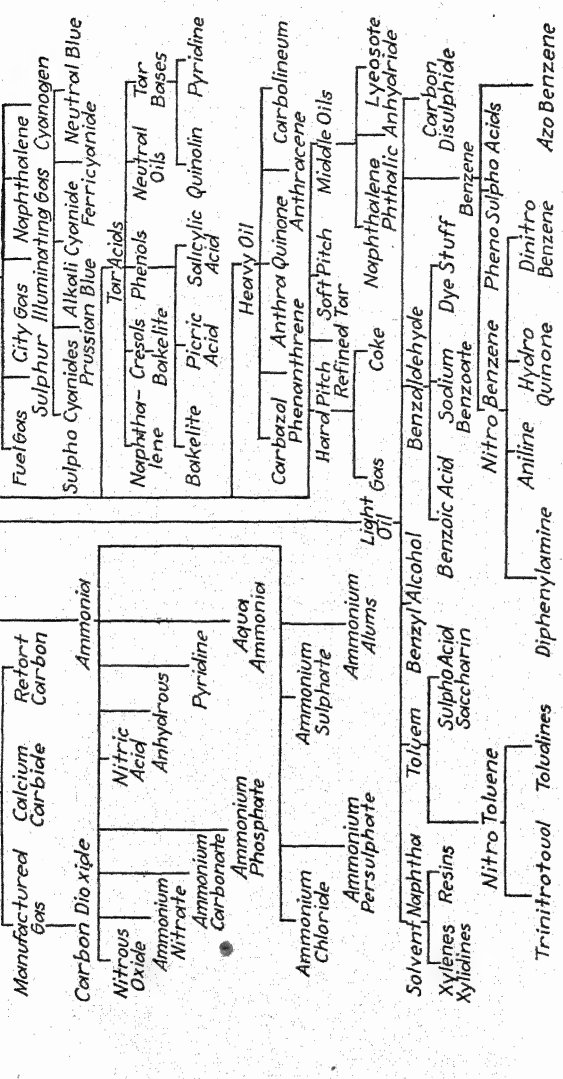

FIG. 171.—(*Courtesy of Koppers Construction Company.*)

charging, which is done with hopper-like cars, or lorries, which operate on tracks constructed for the purpose. Another opening is constructed on the top of each oven for conveying away the gaseous vapors to a hydraulic main.

When an oven is to be put into operation for the first time, it must be thoroughly dried and heated before being charged, to prevent the silica bricks from cracking. This must be done slowly and carefully and often requires from four to six weeks. If the best results are to be obtained, the coal for the charge should be pulverized so that 80 to 90 per cent will pass through a one-eighth-inch mesh screen, but this is not necessary in all cases. After charging, all of the openings are closed and sealed except the outlets for the gaseous vapors. The vapors pass to a hydraulic main where they are condensed and separated from their tar and oils. The average time required for coking depends upon the size of the ovens and the character of the coal. Ordinarily this varies from twelve to twenty-four hours, and the average size of the charge depends upon the size of the ovens and may vary from twelve to twenty tons of coal. At the close of the process the end doors are removed, and the coke is pushed out by an electric ram, which travels the full length of the chambers, into special quenching cars in which it is cooled by quenching with water. The coke is then sized by screening, after which it is ready for market.

An average yield of coke and its by-products based upon a ton of coal is

Coke	0.65 to 0.75 ton
Gas	10,000 to 13,000 cubic feet
Tar and oils	7 to 15 gallons
Ammonium sulphate	20 to 25 pounds

Formerly all coke was made in ovens located at the coal fields, but since the by-product process has come into general use, a common practice is to construct the ovens near the steel plants which they serve and to ship the coal to them. This has the advantage not only of delivering coke to the furnaces in first-class condition but also of furnishing a large quantity of fuel gas for operating the plant in general. When practicable, by-product coke plants are also established near large cities, where the surplus gas can be utilized for domestic use. Although most of the coke manufactured is used for metallurgical purposes, it is also rapidly making inroads in the domestic-heating field.

Gas-house Process.—Gas-house coke is itself a by-product. It is the residue left in the retorts in the manufacture of city gas from bituminous coal. It is generally produced in air-tight iron or fire-brick retorts, is black, very porous, and comes from the retorts in small pieces. It is inferior to either beehive or by-product coke for metallurgical purposes and hence finds its principal use for domestic heating.

Coke Terms

ammonium sulphate—A fertilizer obtained indirectly from ammonia in the volatile matter produced in coke making.

battery—A series or row of coke ovens.

beehive coke ovens—A fire-brick lined oven constructed in the form of a dome or old-fashioned beehive.

breeze—Coke or coal dust.

carbon—A non-metallic element, the principal heating ingredient in coke or coal.

carbonization—Decomposition of coal by heat out of contact with air into coke and volatile matter.

checkerwork—Porous bricks loosely placed in the regenerative chambers for absorbing the heat from the waste gases.

coal gas—Gas obtained from the burning of coal.

coke—Almost pure carbon, obtained from the distillation of bituminous coal. A grayish black, brittle substance.

coking coal—Any bituminous coal that will carbonize into coke.

combustion chamber—A furnace or compartment in which fuel is consumed to produce heat.

Connellsville—A town in southwestern Pennsylvania noted for its coking-coal deposits. Center of beehive-coke industry.

drawing door—The opening in one side at the bottom of a beehive coke oven for discharging the coke.

eye—The opening at the top of a beehive coke oven for charging.

hydraulic main—A main (pipe) for collecting and condensing the volatile matter given off in carbonization of coal in the coking process.

larry (lorry)—A small special car used for charging coal into coke ovens.

quenching—Cooling the hot coke as it comes from the oven by means of water.

ram—A mechanical pusher for forcing (discharging) the coke from a by-product coke oven.

regenerative chambers—Separate compartments supplied with checkerwork of porous bricks for preheating the gas and air used for fuel.

retort—A unit coke oven of the gas-house design.

volatile matter—Gaseous vapors driven off from the coal during the coking process.

Coke Questions

Group I

1. Explain what is meant by coke.

2. Explain what is meant by coking coal.

3. Where are the principal beehive coke ovens located, and why are they located there?

4. Explain the general construction of a beehive coke oven.

5. Explain the shape and operation of a longitudinal coke oven?

6. How is beehive coke designated?

7. How are beehive coke ovens designed as to their position?

8. What industry created a large demand for coke?

9. What fuel was formerly used for iron smelting before coke came into use? Why was its use discontinued?

10. Why is anthracite not so good for iron smelting? Why is bituminous coal not good for iron smelting?

11. What special qualities must coke for blast-furnace use possess?

12. Give the typical yield of coke and its by-products per ton of average coal.

13. Name some of the most important materials obtained from the volatile matter from coking coal.

14. Give the approximate size of a larger by-product unit coke oven.

15. Explain what is meant by breeze in coke production.

16. Explain the use of regenerative chambers in the by-product coke process. What special advantage have the regenerative chambers?

17. What are some of the most important uses for coke?

Group II

18. What is the advantage of having coke ovens in batteries?

19. What happens if we burn the coal in the presence of air? Explain why this is.

20. Why are unit by-product coke ovens constructed narrow?

21. What advantages have by-product coke ovens over beehive ovens?

22. Explain why the bricks in the regenerative chambers are placed in checkerwork and why they are porous.

23. Of what special use is the hydraulic main?

24. Why are by-product coke ovens often placed near blast furnaces?

25. Of what advantage are they near larger cities?

26. What influence did the large deposits of coal have in locating the iron industry in Pittsburgh?

27. In what condition is the coke as it comes from the ovens? What must be done to it immediately?

28. Explain the statement "The coke industry is incidental to the iron industry."

29. Why is gas-house coke called a by-product?

30. Explain why coke floats on water when it is in larger pieces and sinks when it is powdered.

31. Why is less gas noticed in burning domestic coke than in anthracite coal?

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CHAPTER III

IRON AND STEEL

IRON ORES

Iron is so common that we often fail to realize its importance. It is estimated that it comprises about 4.5 per cent of the rocks of the earth's crust, and some authorities even believe that it is the main element of the whole interior of the earth. It is found everywhere in nature but not in its pure state except in meteorites. (It is estimated that 146,000,000 small meteorites fall on the earth each year.) It is responsible for the red in bricks, tiles, terra cotta, and other clay products. It furnishes a base for paints and stains, is taken as medicine, is used in chemicals, and in its metallic form is so woven into the fabric of our everyday life that civilization itself would perish from the earth if the supply should suddenly be cut off. As one author puts it: "Iron and steel have been the world's greatest civilizers."

Historical Sketch.—Biblical records show that iron was used by the Israelites as early as 4000 B. C., and iron relics found in the Egyptian pyramids prove its use in that country as early as 3500 B. C. The Chinese also are known to have used iron several centuries before the Christian era. In the time of Homer, the Greek poet, iron was more precious than gold; even as late as the Revolutionary period of our own country

it was relatively scarce and expensive and used only where wood or some other cheaper material could not take its place. During the last century, however, especially from 1850 to 1900, improved processes of producing iron and steel developed so rapidly that today the industry leads in wealth and magnitude all others except agriculture.

Sources and Classes.—Iron is obtained from ores (rocklike compounds containing the metal and other elements), from which it must be separated before it can be used. The ores, in general, may be classified as igneous, residual, and sedimentary. Igneous ores are the result of the concentrating and solidifying of iron in connection with igneous rock. The magnetites of the Adirondack Mountains are of this class. Residual ores are formed by the disintegration of rocks containing iron and the removal of other materials mixed with it. Certain ores found in Cuba, the Philippines, and other tropical countries are of this type; but not much of this ore is smelted at the present time. Sedimentary ore is the result of chemical reaction between iron compounds in solution and other materials with which they come into contact, especially lime. It is by far the most abundant and most extensively used for smelting.

Kinds.—The principal kinds of ores are hematite, magnetite, siderite, and pyrite. They are also classified according to the percentage of phosphorus they contain as Bessemer and non-Bessemer. Hematite, an oxide of iron, Fe_2O_3, is the ore most abundant and most extensively used in this country for smelting.

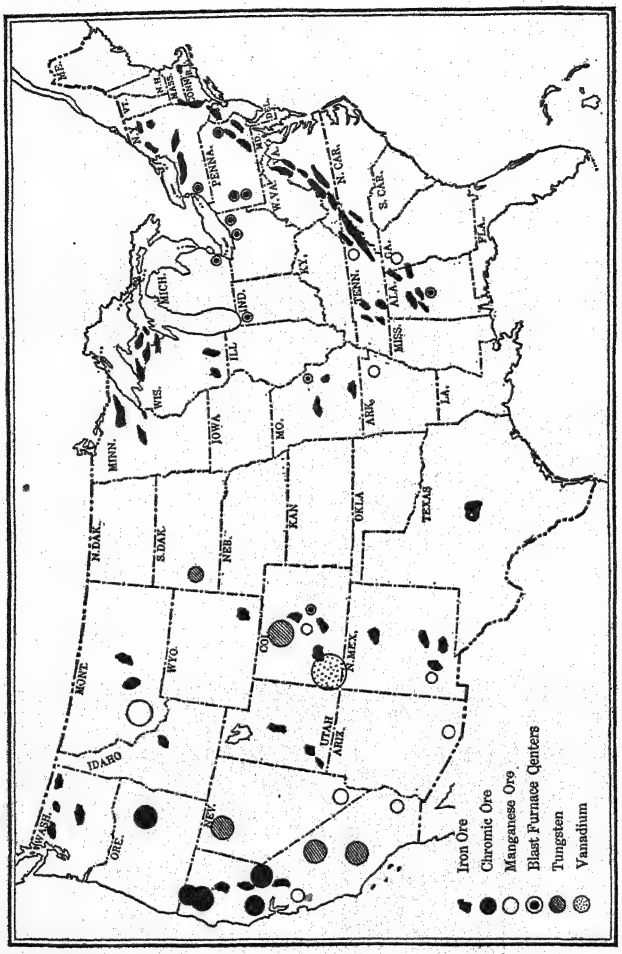

FIG. 172.—Ore deposits in the United States. (*Courtesy of Bureau of Mines.*)

When pure it contains 70 per cent iron. Magnetite is also an oxide of iron, Fe_3O_4. When pure it has as much as 72.4 per cent iron, but its use is limited because of the limited supply. It derives its name from the fact that when rich in iron it has magnetic qualities. Siderite (also called "spathic ore"), is a carbonate of iron, $FeCO_3$. In its richest state it contains 48.2 per cent iron. It cannot compete in this country in the production of iron with the richer and cheaper hematite. It is used in England and on the Continent, where hematite is not easily available and where the richer quality of siderite makes it more profitable for smelting than the siderite found in the beds of this country. Pyrite is an iron sulphide, FeS_2. Its maximum iron content when pure is 46.7 per cent, but it cannot be profitably used for smelting because of its low iron content and high percentage of sulphur, which makes the iron brittle and unfit for heavy service.

The range of ores profitable for smelting at the present time contains from 30 per cent of iron upward, but various factors may enter in to modify conditions under which any certain ore can be used.

Distribution.—Iron ore is very widely distributed over the surface of the earth. It is distributed even more extensively than coal. The United States leads the world in producing iron, with France coming second, Newfoundland third, Cuba fourth, Brazil fifth, and the United Kingdom sixth. These positions, however, are only relative, for the enormous reserves of Brazil might easily place that country ahead of France

and even the United States if they were thoroughly developed. The best quality of iron (Swedish iron) comes from high-grade magnetic ores found in Swedish Lapland. These deposits are limited, however, and usually supply only local demands. They supply

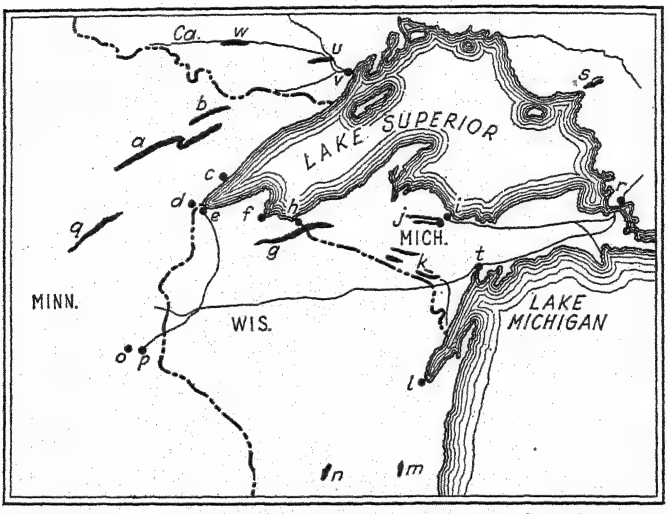

FIG. 173.—Iron mines and ore shipping ports, Lake Superior region. *a*. Mesabi Range. *b*. Vermilion Range. *c*. Two Harbors. *d*. Duluth. *e*. Superior. *f*. Ashland. *g*. Gogebic Range. *h*. State line. *i*. Marquette. *j*. Marquette Range. *k*. Menominee Range. *l*. Green Bay. *m*. Iron Ridge. *n*. Baraboo Range. *o*. Minneapolis. *p*. St. Paul. *q*. Cuyna Range. *r*. Sault Sainte Marie. *s*. Michipicoten District. *t*. Escanaba. *u*. Mattawin District. *v*. Port Arthur. *w*. Atikokan District.

industry in general only when a special high grade of iron is required.

Lake Superior Deposits.—The iron-ore deposits of the United States are chiefly around the Lake Superior district, in the Eastern Highlands, and in Colorado (Fig. 172). Minor workable deposits are found elsewhere in the South and West. The beds of the

Lake Superior region furnish nearly three-fourths of all the ore smelted for iron in this country and nearly one-half of that used in the world. This area comprises nearly 180,000 square miles including parts of Minnesota, Michigan, Wisconsin, and Ontario in Canada. The deposits are in mountain ranges extending roughly from east to west, the most important being the Mesabi, Cuyuna, and Vermilion ranges of Minnesota, the Marquette range of northern Michi-

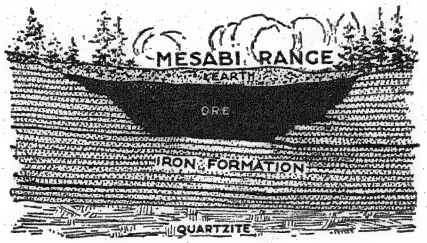

Fig. 173a.—Mesabi Range.

gan, and the Gogebic and Menominee ranges of northern Michigan and Wisconsin (Fig. 173). The ore is chiefly hematite with a limited amount of magnetite, and the deposits are well defined and vary in depth from the surface to 3,000 feet or more. A large percentage of the ore is soft and lies practically on the surface so that it can be easily obtained by open-pit mining with the steam shovel, but in some places it is hard and deep and must be blasted loose.

The Mesabi Range is located in St. Louis and Itasca counties, Minnesota, and extends about 112 miles northeast-southwest; it is from ⅜ to 3 miles wide and lies from 1,400 to 1,900 feet above sea level. It is the greatest of all Lake

Superior Ranges. The ore produced is a hydrated hematite with some limonite, varying in texture from a very fine dust to a fairly coarse, hard, and granular ore. The range has shipped 1,074,981,491 tons through 1939. In 1939, eleven mines in the United States produced over 1,000,000 tons of ore, nine of which were in the Mesabi Range:

	Tons
Hull Rust	114,540,504
Mahoning	66,845,977
Adams	61,582,592
Mesabi Mountains	54,473,716
Fayal	36,444,749
Hill Annex	22,819,647

At the present time the Mesabi Range is the most important for production. The eastern section of this range lies north of the Lake Superior shipping ports, about fifty miles from Duluth. At this point is located Hibbing, the so-called "iron capital of the world" (and incidentally the richest village); and near by is the famous Hull Rust mine out of which during one year of the first World War enough ore was taken to make iron sufficient for a fence nearly halfway round the earth. This great open-pit mine is nearly 2 miles wide, 2½ miles long, and 300 feet deep in its lowest point.

Lake Transportation.—For the most part, the ore from the Lake Superior region is shipped by rail to upper lake ports whence it is reshipped by boat to the lower lake cities for smelting. The principal shipping ports of Lake Superior are Duluth and Two Harbors in Minnesota, Superior and Ashland in

northern Wisconsin, and Escanaba and Marquette in northern Michigan. From the Lake Superior ports the boats pass to the Soo Canal and are "locked down" (about fifty feet) to Lake Huron, where a part of them turn south and pass through Lake Michigan to supply the furnaces at Gary, Ind., and other plants in the vicinity. At the present time the steel plant at Gary

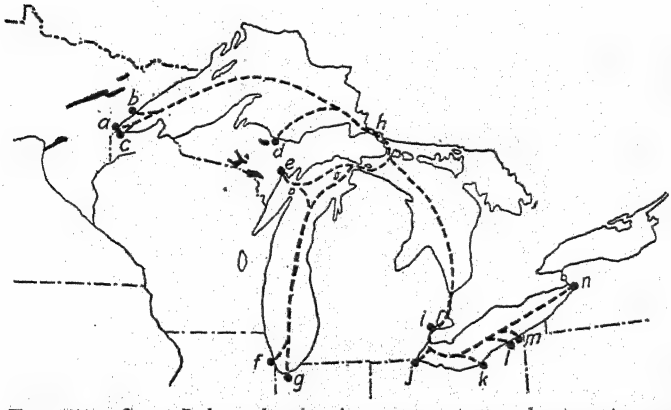

FIG. 174.—Great Lakes, showing iron ore ports, ore boat routes, and main smelting centers. *a.* Duluth. *b.* Two Harbors. *c.* Superior. *d.* Marquette. *e.* Escanaba. *f.* Chicago. *g.* Gary. *h.* Soo Canal. *i.* Detroit. *j.* Toledo. *k.* Cleveland. *l.* Ashtabula. *m.* Conneaut. *n.* Lackawanna (Buffalo).

is the largest of its kind in the world. The remainder continue down Lake Huron through Lake St. Clair into Lake Erie and supply the furnaces at Detroit, Cleveland, Ashtabula, Conneaut, Buffalo, and other Eastern cities (Fig. 174). The ore is shipped in specially constructed boats some of which have a cargo capacity of more than 15,000 tons. Enough boat loads pass through the Soo Canal yearly to make a greater freight tonnage than passes through

either the Suez or the Panama Canal, although the shipping season is only about two-thirds of the year. The boats are loaded at the shipping ports by gravity from high ore docks and are unloaded at their destination by large mechanical unloaders that take several tons at a trip. The boats carry anthracite coal on the return journey to supply the cities of the upper lake region and the far Northwest.

From the Lake Michigan ports the streams of boats also divide, a part going to the furnaces in the Chicago district and the remainder to the lower lake cities of Detroit, Cleveland, Buffalo, etc. A certain amount of Lake Superior ore is also reshipped by rail from Lake Erie ports to Youngstown, Ohio, Pittsburgh, Pa., and other inland steel plants in that district.

We naturally wonder why blast furnaces are located so far from the ore beds. Several reasons can be given: In the first place, many of the present steel plants were constructed in the vicinity of western Pennsylvania and northern Ohio when the bulk of ore used for smelting was obtained from deposits in these districts. The expense of moving these plants to the present ore fields would be enormous and more than offset any advantage gained by shorter ore transportation. Coke, the principal smelting fuel, is made largely in the Pittsburgh district, because of the excellent coking-coal deposits found there. If handled to any great extent, coke breaks up into small pieces called "breeze" (braise) and is unsuitable for smelting. It is better, therefore, to ship the ore

to the coke rather than the coke to the ore. Then, again, the markets for iron and steel products are much better in the more thickly populated sections of the East than in the West, as are also facilities for transportation and export trade.

Other Important Deposits.—Another important ore-producing section of this country is in the lower Appalachian highlands, especially in northern Alabama. Here in the same valley are deposits of rich ore, coking coal, and limestone in such proximity that pig iron can be produced more cheaply there than anywhere else in the United States. Because of this advantage large steel works have been erected at Birmingham, Ala., and elsewhere, which promise to increase rapidly as the demands for iron products increase in that part of the country. This situation is of especial economic advantage to the whole South. It provides labor and makes business for a large proportion of the population. Its products are scattered far and wide to build railroads, ships, and skyscrapers and to furnish supplies for other industries, at a cost that can compete with the largest steel mills of the north.

From her ore beds Colorado is producing considerable iron, which generally goes to supply needs in the Middle West. Here also are found ores and coking coals near enough together to eliminate the expense of long transportation.

The mines of the Adirondacks are supplying the bulk of magnetite used in this country at the present time. This ore is shipped to Buffalo and other iron-

smelting centers and used for special-quality iron. Sometimes it is mixed with hematite to increase the output of the blast furnaces. And we are still obtaining considerable quantities of ore from Pennsylvania, West Virginia, New Jersey, and other Eastern states, but the amounts from these states are relatively insignificant compared with that produced in the Lake Superior region.

Iron-ore Terms

Ashland—An ore-shipping port in northern Wisconsin on Lake Superior.

beneficiation—The process of removing impurities from ore, as water, worthless rock, etc., before it is smelted, by drying, roasting, use of a magnet, etc.

bog ore—Soft ore deposited in a bog or swamp.

car dumper—A machine that lifts and dumps a whole carload of material at one operation.

Escanaba—The principal ore-shipping port in northern Michigan, on Lake Michigan.

hematite—An oxide of iron (iron ore) most extensively used for iron production. Formula Fe_2O_3.

Hibbing—The principal ore town, in the ore district of Minnesota, about fifty miles from Duluth.

igneous ore—Ore formed by cooling and solidifying from the molten state.

limonite—A hydroxide of iron, sometimes called "brown hematite." The only practical difference from hematite is more water in combination.

magnetite—An oxide of iron, the richest iron ore known, sometimes magnetic, hence the name "magnetite." Formula Fe_3O_4.

meteorite—A metallic substance fallen from space, sometimes nearly pure iron or iron and nickel.

open-pit mine—A mine in which the ore lies on the surface and can be obtained without tunneling.

ore boat—A boat constructed especially for transporting iron ore on the Great Lakes. Generally a whaleback with one large hold, sometimes 15,000 tons capacity.

overburden—Gravel or other earthy matter which covers coal or ore beds and which must be removed before open-pit mining can be carried on.

oxide of iron—An iron ore with oxygen as its main impurity; also iron rust.

pyrite—A sulphide of iron; iron ore containing a large percentage of sulphur as its main impurity.

residual ore—Ore formed by the process of dissolving foreign materials combined with it, leaving only the ore.

sedimentary ore—Ore formed by the chemical reaction of iron in solution with other materials with which it comes into contact, especially lime.

sulphide of iron—An iron ore with sulphur as its main impurity.

Two Harbors—Iron-ore shipping port in Minnesota on Lake Superior.

unloader—A machine that unloads iron ore from boats and cars, by power, generally electric.

Iron-ore Questions

Group I

1. About what percentage of the earth's crust is supposed to be iron?

2. Where do we find pure iron in nature?

3. Name some uses for iron not in its metallic form.

4. What is said of iron in the time of Homer, the Greek poet?

5. What do Biblical records show about the early use of iron?

6. Name the principal iron-producing ranges of the Lake Superior region.

7. Name the principal kinds of iron ore, and tell which is best for smelting and why.

8. Name the principal kind of iron ore used in this country, and tell why this is used most.

9. Explain why siderite is used extensively for iron smelting in Europe and why it is not used in this country. Why is pyrite not a good iron-producing ore?

10. Name some of the world's largest iron-producing countries in the order of their importance.

11. Name the principal iron-producing states.

12. Name the principal iron-ore shipping ports of Lake Superior and also of Lake Michigan.

13. Name and locate some of the principal iron-smelting cities that are supplied with ore from the Lake Superior region.

14. Give special reasons why the iron-ore deposits of the South are of special importance to that section.

15. Trace two ore-boat routes from Lake Superior ports.

16. What is meant by an element?

17. Explain how the bloomery worked.

Group II

18. How was iron probably first discovered?

19. Does the fact that we find copper or bronze implements of an earlier date than iron implements prove that copper or bronze was known before iron?

20. What is iron rust? How would this effect the age-of-iron implements?

21. How could we determine from their chemical formulae which is richer in iron—magnetite or hematite?

22. What is meant by the chemical formula of iron ore?

23. Name and explain special advantages of lake transportation over rail transportation in shipping iron ore.

24. Why is it necessary to analyze iron ore before smelting?

25. Explain two methods of testing for the presence of iron ore below the surface of the earth.

26. What are some of the factors that determine whether or not an iron ore is worth smelting?

27. What particular advantage has the practice of transporting coal in the return journey of the lake ore boats?

28. What is meant by the terms "iron oxide" and "iron sulphide"?

29. Name some of the factors that determine the expense of producing iron ore.

30. Why do iron pipes often become stopped up sooner than lead or brass pipes?

31. In what sense is iron the world's greatest civilizer?

32. Why is Swedish iron of specially good quality?

33. Why do we find the iron and steel industry largely in western Pennsylvania and northern Ohio?

34. Why has the center of the iron and steel industry a tendency to move westward?

35. Why is the modern jack-plane cutter sometimes called the plane "iron"?

36. What connection did early iron smelting in this country have with the forests?

37. Why did the iron smelters have to be moved from time to time in our early history?

38. Compare the production of iron in the early bloomery with that of the modern blast furnace.

39. Explain why blast furnaces are located along Lake Erie.

40. What particular advantage is the iron-smelting industry to the cement industry?

SMELTING

Historical Sketch.—Like many other industries, the production of iron dates back before the dawn of recorded history, and the process used in its production in very early times must have been crude and primitive.

We have no record of the first apparatus for the purpose used but know that a very early form of furnace was simply a pit in the side of a hill facing the

prevailing winds, which furnished the blast (Fig. 175). Wood from near-by forests furnished charcoal. It is interesting to note that charcoal is still the best fuel for smelting when a high-grade iron is required. The only reason that it is not used more extensively at the present time is that its supply is limited and its cost prohibitive. As the winds could not always be

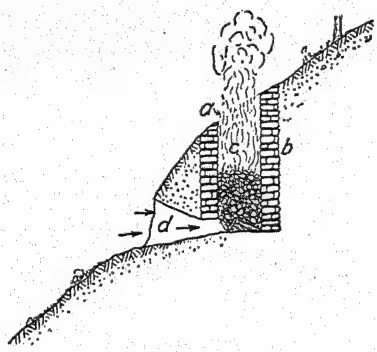

FIG. 175.—Author's sketch of an ancient blast furnace in hillside. *a.* Top of pit. *b.* Crude retaining wall. *c.* Charge. *d.* Natural blast of wind.

relied upon, some artificial means of producing the blast must have been invented to take its place. The first known device for this purpose was a crude goat-skin bellows which was worked by hand or, to be exact, by hand and foot. The bellows was inflated by lifting on a string attached to one side and deflated by the operator's placing his bare heel over the intake hole and pressing downward. A hollow bamboo served as a tuyere; and by working two bellows side by side a fairly continuous blast could be maintained. Devices of this kind can still be seen in operation among the primitive peoples of the East.

The real forerunner of our modern blast furnace, however, was the Catalan forge which originated in Catalonia, Spain. This forge consisted of a rough masonwork structure lined with refractory material (Fig. 176). The blast was furnished by a bellows, worked by hand, by water power, or by a water blower known as an "Italian trompe" (Fig. 178), and was led into the melting zone by one tuyere which passed through the side wall. The quantity of iron made in these crude furnaces was small and expensive,

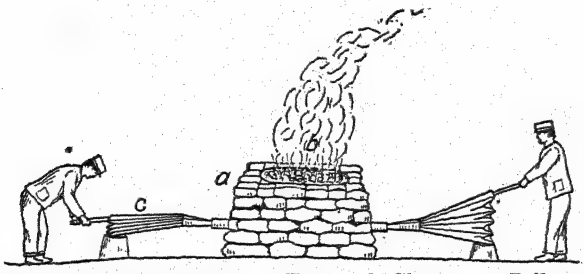

FIG. 176.—Catalan forge. *a*. Forge. *b*. Charge. *c*. Bellows.

but for many years it was sufficient to supply the needs of all Europe and even some for export trade.

When iron making came to America with the early settlers, the Catalan type of forge was the first to be used, and for many years the product of these forges ("bloomeries," as they were called) was the only iron available. In the process of making, the ore was not melted but reduced to a pasty mass that could be hammered practically free from slag and fashioned into any form desired. If care was exercised in this process, a high grade of iron was the result. The famous chain stretched across the Hudson River at

West Point during the American Revolution to block the British boats was forged from iron made in the Sterling forge (bloomery) in Orange County, New York. Small bloomeries of this type were scattered far and wide over the whole country and in the time of Washington were more numerous than blast furnaces are today. This slow system of iron making, how-

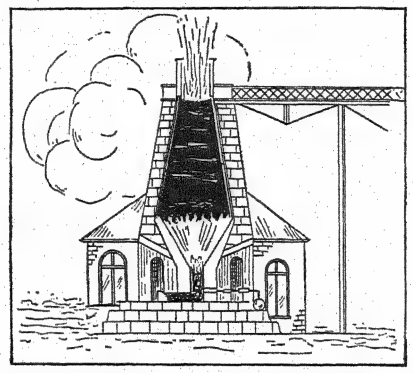

FIG. 177.—Early blast furnace. (*Courtesy of Reading Iron Company.*)

ever, could not long supply the demands of our rapidly increasing population, especially after the beginning of railroad building.

Blast Furnace.—About the middle of the past century, the modern type of blast furnace came into general use. At first, anthracite coal was the principal kind of fuel used, but later its place was taken by coke, which proved the better fuel for production on a large scale and for a uniform grade of good iron.

The modern blast furnace consists of a huge, circular steel shell lined with refractory material from 90 to 100 feet high and about 25 feet in diameter

at its largest point. It is divided into three general zones or sections: the stack, the bosh, and the hearth (Fig. 180). The stack is the upper section and comprises about two-thirds of the height of the whole furnace. It is larger at the bottom than at the top to ensure the proper settling of the charge when the

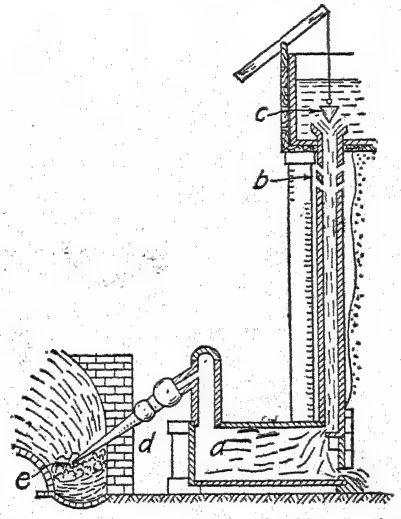

FIG. 178.—Italian trompe. *a*. Tank. *b*. Air intake. *c*. Valve. *d*. Tuyere. *e*. Charge. (*Courtesy of Frederick A. Stokes Company.*)

furnace is in operation. The bosh is the central zone and is in the form of an inverted frustum of a cone, or huge funnel, to retard the settling movement until melting can take place. The hearth is the bottom zone into which the molten iron and slag collect. Embedded in the lining of the bosh and extended in the bottom part of the stack as well as top part of the hearth are bronze or copper tubes through which water circulates to counteract the intense heat

which would otherwise soon destroy the lining. A large pipe called the "bustle pipe" encircles the bosh and distributes the blast to the tuyeres which in turn deliver it to the upper part of the hearth where it is needed for melting. The tuyeres are short, special

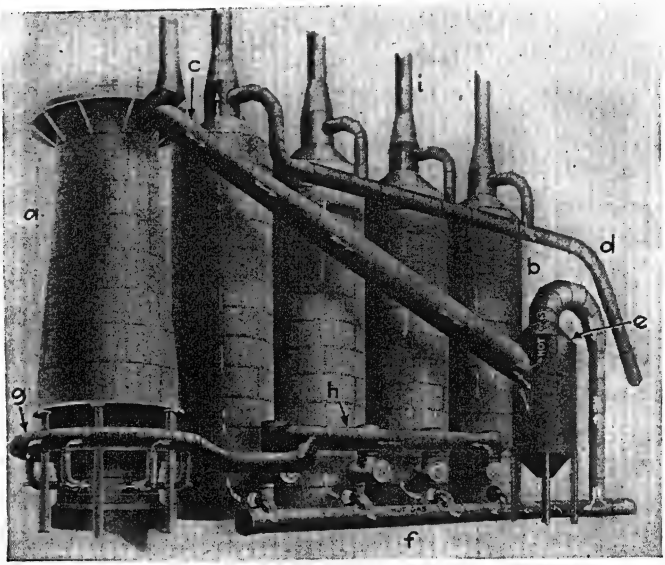

FIG. 179.—Blast-furnace unit with four stoves. *a.* Blast furnace. *b.* Stoves. *c.* Down-comer pipe. *d.* Cold-air pipe. *e.* Dust catcher. *f.* Hot-gas pipe. *g.* Bustle pipe. *h.* Hot-blast pipe. *i.* Stack. (*Courtesy of American Steel and Wire Company.*)

pipes connecting the bustle pipe with the furnace proper. They are generally from ten to sixteen in number and are arranged around the furnace like the spokes of a great wheel with the hearth for the hub and the bustle pipe for the rim. At the lower bend in each tuyere is an "eyesight," an opening through which the operator can see and determine conditions in the

melting zone. The upper end of the stack, or throat, is closed by a double bell-and-hopper device which permits of charging the furnace without allowing the gas to escape; and just below the throat, openings lead to the down-comer pipe which conveys the waste gases to dust catchers and scrubbers whence they are led to the stoves for preheating the blast or to the engine room for producing power.

Blast-furnace Stoves.—Connected with each furnace are four or five stoves for preheating the air before it is used in the blast (Figs. 179, 181). These stoves are huge, circular steel shells nearly as large as the furnace itself (Fig. 182). They are lined with refractory material and have a porous, fire-brick checkerwork inside that allows for the free circulation of the gases and air. Waste gases from the furnace are burned in these stoves and heat the porous bricks which in turn give up their heat to fresh air circulating through the interstices before it is used in the blast. As a rule, one stove is discharging hot air while the other three are being gassed, the valves being shifted to a fresh stove once every few hours to keep the blast at a uniform temperature. When the fifth stove is used, it is generally for the purpose of allowing one stove to be cleaned and repaired without interfering with the continuous operation of the other four.

Operation of Blast Furnace.—When a furnace is to be "blown in" (started), it must be thoroughly dried before the regular charge can be introduced. This often requires from two to three weeks and is accomplished by slowly burning wood, or gas, and coke in

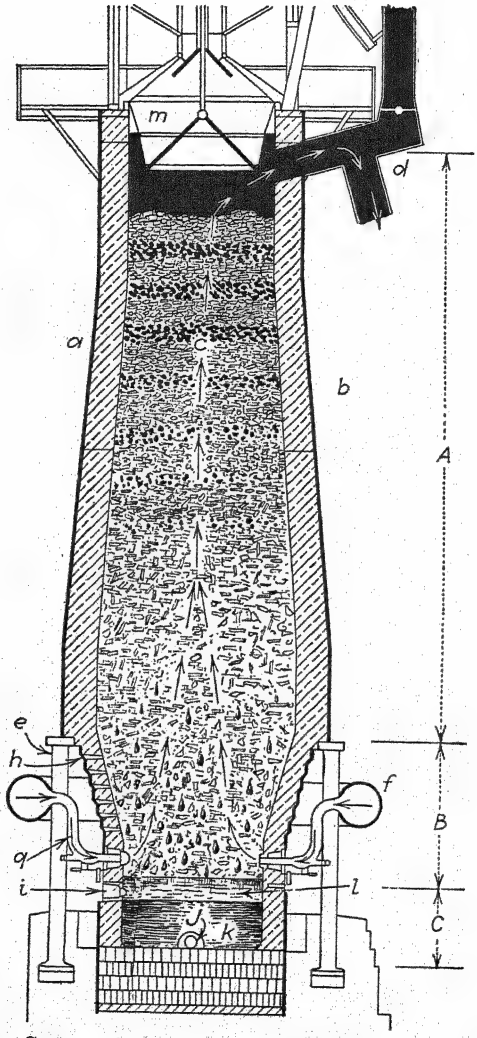

FIG. 180.—Cross-section of modern blast furnace. *a*. Steel shell. *b*. Refractory brick lining. *c*. Charge. *d*. Down-comer pipe. *e*. Supporting column. *f*. Bustle pipe. *g*. Tuyeres. *h*. Cooling tubes. *i*. Cinder notch. *j*. Tap hole. *k*. Molten iron. *l*. Molten slag. *m*. Bell and hopper. (*Courtesy of American Steel and Wire Company.*)

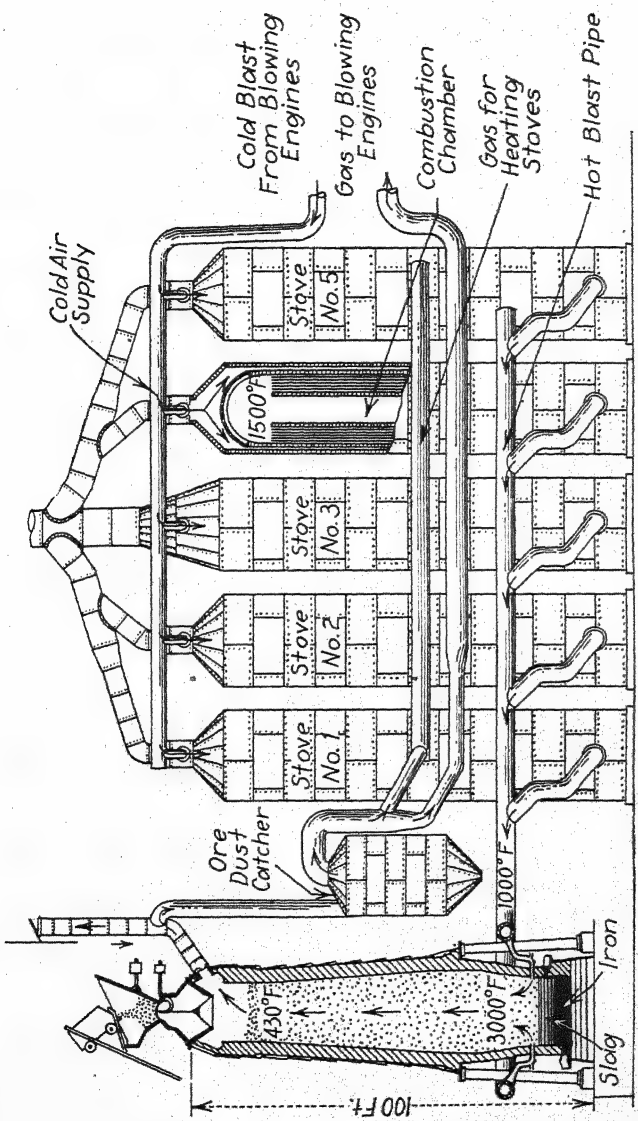

FIG. 181.—Blast-furnace unit with five stoves. (*Courtesy of Minnesota Steel Company.*)

the interior and gradually adding small charges of ore, coke, and limestone until the furnace is full. The regular charge, as has been suggested, consists of ore, coke, and limestone (flux). Skip cars haul the materials up an inclined trestle or jack ladder from the bins below and dump them into the receiving hopper

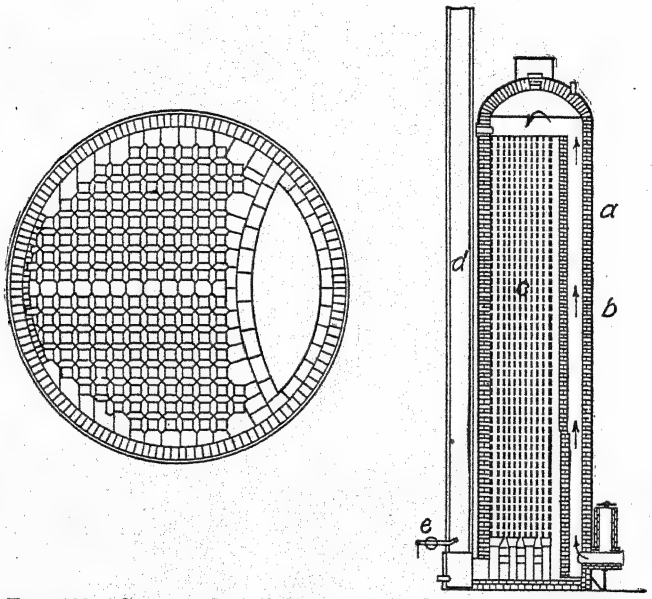

FIG. 182.—Cross-section of blast-furnace stove. *a*. Steel shell. *b*. Refractory lining. *c*. Porous brick checkerwork. *d*. Stack. *e*. Damper. (*Courtesy of Harbison-Walker Refractories Company.*)

of the bell-and-hopper charging device at the top. These skips are constantly on the job and are as regular as clockwork, for once a furnace is started it is never allowed to stop except for repairs, labor troubles, lack of market for the iron, or some other special reason. Instances have been known where furnaces have run continuously for a year and even longer.

One of the most important parts of the whole process is "burdening the furnace," that is, determining the exact proportions of ore, coke, and flux required for the charge. Formerly this knowledge was considered to be a sort of special gift possessed by the head operator, but in modern times it is based entirely upon a careful analysis of the materials in the laboratory. A furnace producing 500 tons of pig iron per day requires approximately 1,000 tons of ore, 250 tons of limestone, 500 tons of coke, and, with a blast of from 15 to 21 pounds pressure per square inch, 60,000,000 cubic feet of air. These proportions may vary somewhat with the nature of the raw materials and the care with which the furnace is operated. The temperature required for smelting ranges from 2500 to 3000°F. for ordinary ores.

As the process advances, the molten iron and slag collect in the hearth and are drawn off at intervals of four to five hours. The iron, being heavier than the slag, settles to the bottom and is drawn from the tap hole near the bottom of the hearth, while the latter floats on the top and is drawn from the cinder notch higher up. As the iron leaves the furnace, it is cast into pigs on a sand casting floor or in a casting machine (an endless steel-link belt supplied with moulds) or is taken directly to the mixers and kept in a molten state until used for making steel.

One Furnace and Four Stoves to Heat the Blast.—Four stoves accompany each furnace. They are lined with fire brick and heated red hot. Only one stove at a time is used to make hot blast for the furnace. Forty to sixty

thousand cubic feet of cold blast per minute from blowing engines enter the one hot stove while the other three are being heated. The cold blast is shifted to a fresh hot stove every two or three hours. Heated to 1200°F., the blast passes through the hot-blast main to the bustle pipe around the furnace; then down and through the water-jacketed tuyeres into the furnace at the hottest point, 3500°F. The blast pressure is usually 15 pounds per square inch. This hot blast furnishes about one-fifth of the total heat of the furnace. Before the blast is heated it is refrigerated to take out moisture, heating and refrigerating increasing the efficiency over old-fashioned cold blast 70 per cent. The blast, passing up through the furnace, becomes heavily impregnated with gas and rushes out through the down comer. This gas is loaded with coke dust and other particles swept up while passing through the furnace, which are dropped in a dust catcher, from whence the gas passes upward and downward through the hot gas main in a red-hot gush of fire into three of the stoves and out through the tall chimneys. A furnace makes more gas than necessary to heat its stoves, so some of it is diverted to boilers, making steam for blowing engines, or is further cleaned and used to run gas engines for blowing.

Electric Iron Smelting.—Within the past few decades electric furnaces for smelting iron ore have been developed. They are used, however, more in Sweden, Norway, Italy, and Japan—countries with limited supplies of coal—than they are in the United States.

A typical electric iron-smelting furnace is somewhat like the regular blast furnace using coke for fuel. It consists of a shaft, bosh, and hearth (Fig. 183).

It has the usual bell-and-hopper device for charging and usually three tuyeres for conducting gases into the free space above the charge for cooling the roof

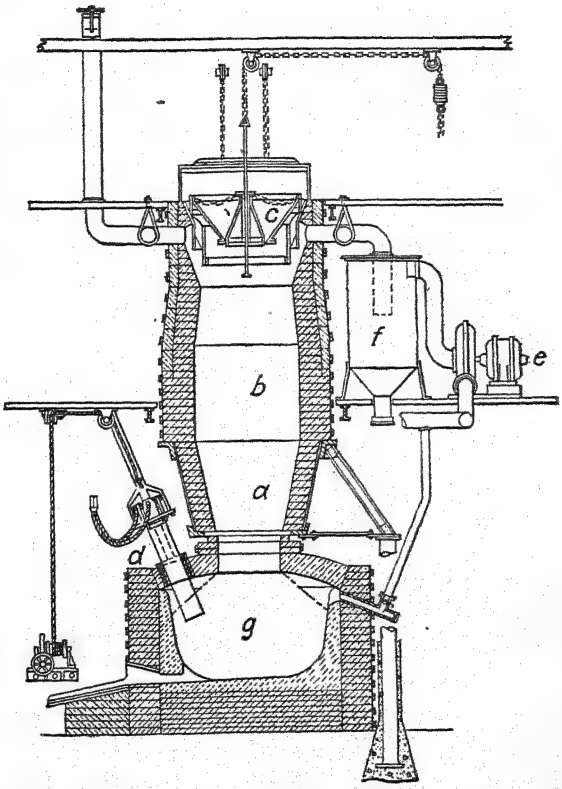

FIG. 183.—Electric iron-ore smelting furnace. *a*. Bosh. *b*. Stack. *c*. Bell and hopper. *d*. Electrode. *e*. Fan motor. *f*. Dust catcher. *g*. Hearth. (*After Stoughton.*)

of the hearth. Four or eight carbon electrodes project through the roof to furnish an arc for smelting. A certain amount of carbon (coke or charcoal) is introduced into the charge to act as the reducing agent and

to increase and distribute the heat evenly. The quality of pig iron obtained depends upon the grade of ore used and the care exercised in operating the furnace.

Up to the present time electric iron-ore smelting has not, as a general proposition, been able to compete in this country with regular blast-furnace smelting, but its development, thus far, gives promise of a future source of iron and steel supply in case our present methods should become inadequate or fail.

As is seen, pig iron is the first product from the ore. It is the raw material from which all other irons and steels are made. It often contains as much as 4 per cent carbon, also sulphur, phosphorus, manganese, silicon, and other impurities which render it hard, brittle, and weak, unsuited for any purpose except where bulk and compression strength are the main considerations.

Smelting Terms

bell and hopper—A device at the top of the blast furnace to admit the charge without allowing the gases to escape.

blast—The air blown into the furnace to increase the temperature.

bloomery—Early forge in which ore was smelted to produce iron.

bosh—The central zone of the blast furnace.

blast furnace—A large upright furnace for smelting iron ore which uses a blast of air to increase the temperature.

bronze tubes—Tubes of bronze or copper embedded in the lining of the bosh (principally) for the circulation of water to counteract the intense heat.

burdening the furnace—Determining the proper proportions of ore, coke, and limestone for the blast-furnace charge.

bustle pipe—The large air duct encircling the furnace to deliver the blast to the tuyeres.

casting machine—A series of iron moulds on an endless-belt conveyor to receive and cast the molten pig iron into form as it comes from the furnace.

charge—The iron ore, coke, and limestone introduced into the blast furnace to produce pig iron.

cinder notch—An opening near the upper portion of the hearth for drawing off the slag.

down-comer pipe—A large pipe leading from the top zone of the furnace for conveying away the waste gases.

dust catcher—A large steel apparatus for separating the dust from the waste gases.

eyesight—A window or other opening in a tuyere through which the operator can see into the melting zone of the blast furnace.

flux—Generally limestone mixed with the charge to reduce the melting point and assist in removing the impurities from the ore. (Oyster shells are sometimes used.)

hearth—The lower zone of the blast furnace, where the molten pig is collected.

melting zone—The hottest part of the furnace, where the melting takes place.

pig iron—The first product from the ore. Crude iron as it comes from the blast furnace.

sand floor (casting floor)—A sand bed in the floor near the blast furnace into which the molten pig is run to be cast into convenient sizes for handling.

scrubbers—Special apparatus for cleaning the waste gases (with water) before they are used for the engines.

shaft—The upper zone of the blast furnace.

sinter—To cause to come to a solid mass by heating without thoroughly melting.

skip—The small car that conveys the charge to the top of the blast furnace.

slag—The impurities formed in the blast furnace by the uniting of the flux (limestone) with the impurities of the ore.

sow—The main channel in a sand casting floor.

stove—A large steel furnace or oven connected with the blast furnace to preheat the blast before it is introduced into the furnace proper.

tap hole—The hole at the bottom edge of the hearth in a blast furnace for drawing off the molten pig iron.

tripper—A device for tipping and dumping the skip at the top of the blast furnace.

tuyere—A special air duct leading from the bustle pipe to the melting zone.

Smelting Questions

Group I

1. What was used for fuel in early iron smelting? What can you say of the use of this fuel at the present time?

2. What was the earliest type of iron furnace used in this country, and where did it originate?

3. Explain the process of producing iron in the early bloomeries.

4. Name a bloomery of Revolutionary times and mention a famous article that was made in it for use in the war.

5. Give the general size and name the main parts of a large modern blast furnace.

6. Why must the fuel (coke) be of large size and strong for use in the blast furnace?

7. Name the materials of the blast-furnace charge.

8. Give the number generally used and explain the purpose of the stoves connected with the blast furnace.

9. Give the general proportions of the charge of a blast furnace producing about five hundred tons of iron per day. What would cause these proportions to vary?

10. Explain the process of blowing in a blast furnace.

11. State reasons for shutting down a blast furnace.

12. Name two uses for the gases from a blast furnace.

13. What is the range of temperatures required for smelting iron ore?

14. In what countries are electric smelting furnaces used most extensively? Explain why they are used there.

15. Explain the action and purpose of the bell and hopper.

16. How is the charge carried to the top of the blast furnace?

Group II

17. What is meant by the prevailing wind?

18. In what way do the materials of the flux affect the quality of the iron?

19. Mention some of the factors that might affect the quality of the iron in smelting.

20. What material produces the slag?

21. Give reasons for the particular shapes of the major parts of the blast furnace.

22. Explain why a number of smaller tuyeres distributed around the blast furnace are better than one large one in one place.

23. Give reasons why it is profitable to run a blast furnace continuously.

24. Name some of the principal points that an engineer must consider in designing a blast furnace.

25. Why does it take so long to blow in, or start, a blast furnace?

26. What two contributions does coke make in iron smelting?

27. What might happen if a blast furnace started before it was thoroughly dried?

28. How can we determine the amount of water that is blown into a blast furnace in twenty-four hours?

29. What is meant by scrubbing gas?

30. How should we determine the proportions of coke and limestone to use with a certain grade of ore?

31. Name the three major uses for pig iron.

32. In sintering ore is melted just enough to cement it into lumps. Explain when this is apt to be done and its advantage.

33. What would determine the number of stoves to use with a blast furnace?

34. Give two reasons for the use of the dust catcher.

35. Why should the gas pass through scrubbers before it is used in the engines?

36. Give an important reason why it is profitable to have a steel plant combined with a blast-furnace plant.

BESSEMER STEEL

Origin of Bessemer Process.—A large percentage of the output of pig iron goes, while still in a molten state, directly for the production of steel by either the

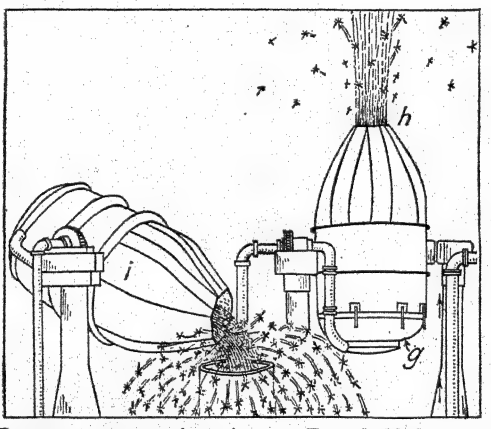

FIG. 184.—Bessemer converter in action. *g.* Detachable bottom. *h.* Nose. *i.* Furnace tilted. (*Courtesy of Joseph T. Ryerson & Son, Inc.*)

Bessemer or the open-hearth process. Up to 1856 steel was made entirely by the costly crucible or cementation processes, but in that year Sir Henry Bessemer, an Englishman, invented a method by which a medium grade of steel could be produced by blowing a blast of cold air through (oxidizing) molten pig iron. An American by the name of Kelley also claimed to have discovered the same principle a few years before this and was granted a patent on the process in

the United States in 1857. Here was the real beginning of the modern steel industry. The Bessemer process made possible a thousand uses for steel heretofore not dreamed of and at a cost within the reach of all manufacturers. Bridges, farm implements, mining machinery, logging tools, and many other articles that formerly had been made, in part at least, of wood were made of steel, and the number greatly multiplied. The Bessemer converter played an important part in the era of railroad building that developed in this country after the Civil War.

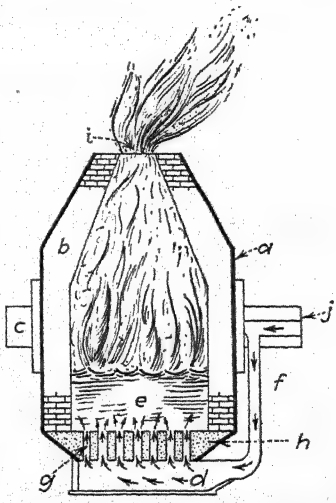

FIG. 185.—Bessemer converter. *a.* Steel shell. *b.* Refractory brick lining. *c.* Trunnion. *d.* Wind box. *e.* Charge. *f.* Air duct. *g.* Tuyeres. *h.* Removable bottom. *i.* Gas flame. *j.* Hollow trunnion.

Bessemer Converter.—The Bessemer converter proper consists of a rigid, pear-shaped, steel shell lined with fire brick, with an eccentric nose or opening at the upper end (Fig. 185). The average furnace of this type is approximately 10 feet in diameter and 15 feet high and has a capacity of 12 to 15 tons of steel per blow, or heat. It is mounted on trunnions to permit being tilted to receive the charge and to discharge the finished product. One trunnion is hollow and serves as an air duct to convey the blast to the wind box, and the other is fitted with a gear

attachment by which the furnace is tilted when in operation. The bottom is made detachable to facilitate removing and making repairs and is supplied with a wind box and tuyere bricks containing many small holes (about 250) through which the blast is led to the charge.

Bessemer Operation.—There are practically two processes for making steel in the Bessemer converter, the acid and the basic, although the operation of the furnace is nearly the same for both. In the acid process the vessel is lined with silica material, and the charge is of pig iron of low sulphur and phosphorus content. In the basic process the lining is of magnesia material, and for the charge a pig iron of considerably higher percentage of sulphur and phosphorus can be used. In England and on the Continent the basic process is common.

Molten pig is brought from the mixer. When the converter is charged, it is tilted on its side to such an angle that the metal will not run into the tuyeres or out at the nose. Sometimes a certain amount of steel scrap is mixed with the charge. After charging, the blast is turned on and the vessel is righted. The air passing through the molten metal causes it to boil violently for about ten minutes, during which time most of the impurities, as carbon, silicon, sulphur, manganese, and phosphorus, are oxidized. A brilliant flame shoots from the nose but gradually dies down as the impurities are burned off, indicating to the operator that the boiling has continued long enough for the good of the steel. The vessel is again

tilted, and the charge is recarburized with a predetermined amount of ferromanganese or spiegeleisen, according to whether soft or hard steel, respectively, is required. (Sometimes anthracite coal is added for recarburizing when a high percentage of carbon is needed.) During the process cold metal, cold steel scrap, or cold pig is sometimes added to the bath to reduce the temperature to the desired point. The furnace is then allowed to boil again, further removing the impurities and thoroughly mixing the added elements. The finished steel is discharged into large ladles and cast into ingots of convenient size for handling. These are taken to soaking pits for solidifying before being rolled or otherwise formed into commercial products.

No branch of the steel industry presents a more spectacular sight than the Bessemer converter in action. The brilliant-colored flame at the nose sometimes shoots into the air more than thirty feet, producing a pyrotechnic display hardly equaled in our Fourth of July celebrations. The furnace seems like a huge, fiery animal roaring, hissing, twisting, and spitting fire at will. No man dares to come near the monster, and only a few are seen in the vicinity. But in reality it is a tame and obedient affair. On a little platform, called the "pulpit," at a safe distance, sits the operator manipulating levers. A slight manipulation of one lever causes the furnace to tilt, another rights it, and still another switches on or turns off the blast; in fact, everything is done by machinery, even to the bringing in of the molten

iron for charging and conveying away the finished steel.

The average Bessemer converter will last for several months before a new lining is necessary and will turn out a large number of heats, if properly handled. This is not true of the bottom, however, where the action of the oxygen of the blast eats away the top of the tuyeres so rapidly that it is necessary to replace them about every day.

Decline in Use of Bessemer Steel.—Up to 1908 Bessemer steel surpassed all other makes in tonnage, but from that date on the output has decreased relatively until at the present time it is less than 25 per cent of that produced in the open-hearth furnace. This condition is largely due to the fact that low-phosphorus Bessemer ores are becoming more scarce and that better and more uniform grades of steel can be obtained in the open-hearth furnace from poorer quality of ores. Bessemer steel no longer plays an important part in the production of railroad rails and structural members; and its prospects of ever again occupying the same important position in other industries that it did in the closing years of the last century are not bright. While the Bessemer-steel industry as such has rapidly declined in recent years, the furnace finds an important place in the production of what is known as "duplex steel." In this process molten pig is first blown in the Bessemer converter to remove some of the impurities and afterward dephosphorized, or finished, in the basic open-hearth furnace.

The principal characteristics of Bessemer steel are strength and ductility, and its present uses are largely for nails, wire, piping, sheets, and similar small articles requiring a moderately priced steel of ordinary strength.

Bessemer-steel Terms

acid lining—The lining of a furnace with silica (or acid) bricks.

acid process—Making steel in a furnace having an acid lining.

basic lining—The lining of a furnace of calcareous material.

basic process—Making steel in a furnace with basic lining.

Bessemer process—The process of making steel by blowing a blast of air through molten pig iron. Named for Sir Henry Bessemer, the inventor.

blow—The name given to the operation of making a batch of steel in the Bessemer converter.

blower—The man who operates the furnace from the pulpit; the operator.

converter—Another name for the Bessemer-steel furnace.

decarbonize—To remove carbon by chemical reaction, generally with oxygen.

deoxidize—To remove oxygen by chemical reaction, generally with carbon.

duplex steel—Steel produced by first refining in a Bessemer converter and afterward completing the process in the open-hearth furnace.

Kelley—An American who, before Bessemer, is said to have used the principle of making steel by blowing air through molten pig iron.

manganese—A hard, brittle, grayish white metallic element.

mixer—A large, refractory-lined container for receiving and mixing the batches from blast furnaces before they are used for steel making.

nose—The opening at the top of the converter for charging and discharging.

pipe—The top part of an ingot containing holes due to the metal's shrinking when cooling and also to gas bubbles.

phosphorus—A soft yellowish-white non-metallic element.

pulpit—The special platform upon which the operator of the Bessemer converter stands.

recarburizing—Introducing spiegeleisen into the converter after the blow to add the desired element.

silicon—A non-metallic element (acid) widely distributed in nature.

stripping—Removing the moulds from the ingots.

teeming—Discharging the molten metal from the bottom of a ladle into the ingot moulds.

trunnion—The axle upon which the converter turns for charging and discharging.

wind box—The compartment in the bottom of the converter that receives the blast and delivers it to the tuyeres.

Bessemer-steel Questions

Group I

1. Who was Sir Henry Bessemer and what contribution did he make to the steel industry? In what year?

2. Who was Kelley and what did he contribute to steel making?

3. Name the two general processes of making Bessemer steel, and explain their main differences.

4. Give the size and capacity of a typical Bessemer converter.

5. Give reasons why the relative importance of Bessemer steel has declined.

6. In general, what takes place in the converter during the blow?

7. Name articles now made of Bessemer steel that were formerly made of wood.

8. What causes the brilliant flame to shoot from the furnace during the blow?

9. Mention several articles made of Bessemer steel at the present time.

10. Why are the tuyere bricks so short-lived? How does the operator know when the blast has been on long enough?

GROUP II

11. Why is the Bessemer furnace called a "converter"?

12. How did Bessemer and Kelley discover their process of steel making?

13. Of what particular advantage to the operation of the furnace is the detachable bottom?

14. What determines how many detachable bottoms will be needed?

15. Explain why the holes in the tuyere bricks are made so small.

16. Name the advantage of using pig for the charge in its molten state.

17. Explain why the temperature is higher at the end of the blow than at the beginning.

18. Why is the blast led through the hollow trunnion instead of through a pipe attached directly to the wind box?

19. Explain the advantage in the use of the Bessemer converter in making duplex steel.

20. Why is it an advantage to have the Bessemer-steel plant near a blast furnace?

21. How did the Bessemer converter play an important part in developing our West?

22. Why should a mixer be large?

OPEN-HEARTH STEEL

Historical Sketch.—At the same time that Bessemer and Kelley were experimenting with a cold-air blast to make steel, other men were working along different lines trying to solve the same problem. In 1845 John Marshall Heath patented a process by which a medium

grade of steel could be produced after the manner of making wrought iron in the puddling furnace. Little progress was made in the development, however, until the furnace was coupled with the regenerative system invented by Siemens about 1860. Here was the start of the process that was to develop into the largest branch of the whole steel-producing industry. The secret was out. Good steel could now be made on a large scale and at reduced cost from ores that could not be used for the Bessemer product. In addition to these advantages, more than 50 per cent of the charge could be steel scrap, which was a very important factor, since there are always large quantities of odds and ends left over around steel mills. This new type of furnace was called the "open hearth" because of the exposed condition of the bath in the hearth, and the process was called the "Siemens-Martin" open-hearth process because it was first used on a commercial scale by Martin of England.

There are two general divisions of open-hearth steel making, known, respectively, as the "basic" and "acid" processes according to whether basic or acid materials are used for the furnace linings and according to the nature of the pig iron employed for the charge.

Modern Open-hearth Furnace.—The typical open-hearth furnace consists of a rectangular, reinforced, fire-brick structure with a dishlike hearth lined with special refractory materials (acid or basic, respectively, according to the nature of the charge used and the grade of steel desired) (Fig. 186). The furnaces vary in size from a few tons capacity to 250 tons or

more. The larger hearths are about 48 feet long, 16 feet wide, and 4 feet deep. In the ends, ports are constructed to admit the flames, and underneath are located regenerative chambers for preheating. The roof is arched and is constructed low for the purpose of deflecting the flames to the charge. Charging doors occupy a large part of one whole side just above

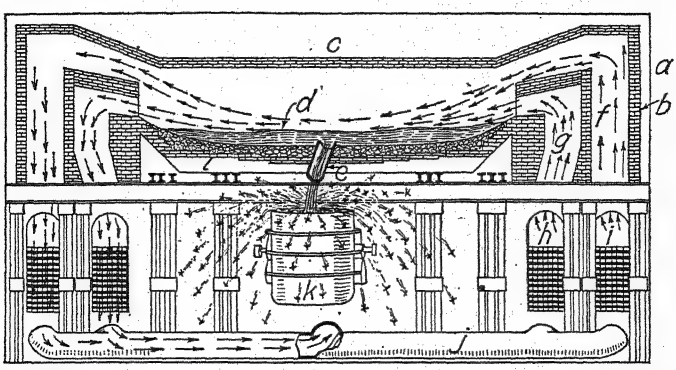

FIG. 186.—Open-hearth steel furnace. *a*. Reinforced outer structure. *b*. Fire-brick lining. *c*. Low arched roof. *d*. Bath. *e*. Top hole. *f*. Air duct. *g*. Gas flue. *h*. Gas regenerative chambers. *i*. Air regenerative chamber. *j*. Gas and air pipe. *k*. Ladle. *l*. Hearth lining. (*Courtesy of Joseph T. Ryerson & Son, Inc.*)

the top of the hearth, and a tap hole is at the center of the other side near the bottom.

Operation.—Before the charge is introduced, the furnace is heated with a gas flame and thoroughly dried. The hearth is then thoroughly sintered with special sand or other suitable material and finally coated over with a wash heat of molten slag which seals up all crevices and ensures a tight working bottom. The charge consists of pig iron, generally in a molten state, and scrap with a small amount of dolomite or

other fluxing material. Small quantities of iron ore (iron oxide) and aluminum are introduced to remove impurities, and alloying elements added to produce the quality of steel desired. At first, the molten pig is poured in from a ladle, and then scrap is added with an iron charging pan (Fig. 187) attached to the end of a long charging peel which conveys the pan to the interior of the furnace and dumps its contents with a simple revolving motion. The fluxing materials and alloying elements are added by hand when needed.

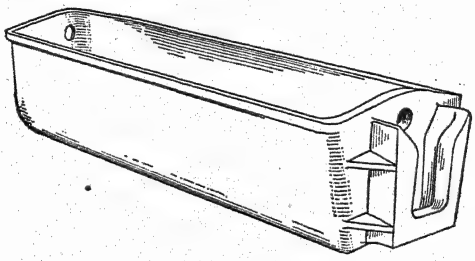

FIG. 187.—Charging pan for open-hearth furnace.

Sometimes a charge of pig iron is partially refined into steel in the Bessemer converter and then mixed in its molten state with the bath in the open hearth for further purification. This practice is known as the "duplex" process and is used to cheapen the cost of open-hearth steel and to produce certain grades of metal. Duplex steel is sometimes further refined in the electric furnace, in which case it is known as "triplex" steel. (On an average, 1 ton of iron ore, ½ ton of coke, and about 600 pounds of limestone are required for ½ ton of open-hearth steel.)

As a rule, producer gas is used for fuel. Natural gas is good when available. Oil can also be used, but the cutting action of its flames on the lining of the furnace

when used alone makes repairs necessary more often and adds to the expense. A tar spray is sometimes mixed with oil or gas and makes a very satisfactory fuel. It also reduces the fuel cost.

When the furnace is in operation, the dampers are switched about every twenty minutes, alternately taking heat from first one set of regenerative chambers and then the other. The flames travel back and forth over the bath, distributing the heat evenly to all parts and melting and refining the steel. As the process continues, a scum or slag blanket collects on the surface, protecting the molten metal from burning or oxidizing. Tests are taken from time to time to determine the progress of the steeling process; and when the metal has reached the desired quality, the flames are turned off, and the furnace is ready for tapping. The time required for a heat is from five to twelve hours, depending upon the size and type of the furnace, the nature of the charge, and the quality of steel desired. Formerly only coarser grades of steel were made in the open-hearth furnace, but in recent years the tendency is to use this type of furnace more and more for higher grade metal. At the present time a large percentage of the steel consumed in automobile construction is made in open-hearth furnaces.

Open-hearth-steel Terms

analyze—To separate into constituent parts or elements for study.

charging pan—The iron pan adjusted on the end of the charging peel for holding the scrap and carrying it into the furnace.

charging peel—A long arm or extension attached to a charging machine for conveying and dumping the scrap in the open-hearth furnace.

crane—A machine for lifting and transporting heavy weights, generally from above.

dolomite—Carbonate of calcium, a special limestone.

duct—An air passage.

flue—A pipe or passageway for gases.

impinge—To strike upon a surface, to press against.

ladle lip—A concave projection at the upper edge of a ladle to guide the metal in pouring.

Martin—The man who first used the open-hearth method of making steel on a commercial scale.

open-hearth furnace—A steel furnace with its bath worked in an open, shallow hearth.

producer gas—Gas produced by blowing air through red-hot carbon, generally bituminous coal.

regenerative chambers—Separate compartments connected with a furnace arranged for preheating the gas and the air used for fuel.

Siemens—The man who connected the open-hearth process of making steel with the regenerative system.

slag blanket—The coating of slag, or scum, that forms on the top of the bath in the open-hearth furnace.

steel scrap—Miscellaneous pieces of steel, old and new, used in the bath for steel making, especially in the open-hearth furnace.

taking a test—Removing a small amount of steel from the furnace to determine its quality.

tilting furnace—An open-hearth furnace that rolls over sidewise to discharge the molten steel.

triplex steel—Steel produced by superrefining duplex steel in the electric furnace.

Open-hearth-steel Questions

Group I

1. What contribution did John Marshall Heath make to steel production? In what year was this?

2. What improvement was made on Heath's invention that helped to make the process a success? Who made this improvement? In what year was this?

3. Explain what is meant by an open-hearth furnace. Give a brief description of this type of furnace.

4. What are the two divisions of the open-hearth process?

5. Give the general composition of the charge of the open-hearth furnace.

6. Give the size and capacity of a large open-hearth furnace.

7. Why is the roof of an open-hearth furnace constructed in the form of an arch, and why is it so low?

8. Give the names of the materials used in the lining of the open-hearth furnace.

9. Explain how the scrap is charged into the furnace.

10. What is the objection to the use of oil for fuel in the open-hearth furnace?

11. What factors determine the time required for producing a batch of open-hearth steel?

12. Explain what is meant by teeming.

13. Explain what is meant by ingots and ingot moulds.

14. Name several uses for open-hearth steel.

15. For what purpose are iron ore and aluminum added to the batch of open-hearth steel?

Group II

16. How does the charge for the open-hearth furnace differ from that of the Bessemer converter?

17. Explain why the hearth of the open-hearth furnace must be shallow.

18. What has the lining of a furnace to do with the nature of the steel?

19. What determines the size and number of the regenerative chambers?

20. What is meant by the slag blanket? What purpose does it serve?

21. Why are open-hearth furnaces constructed with several small charging doors instead of one larger one?

22. Of what advantage is the use of molten pig for the charge instead of cold pig?

23. Where is tar obtained? In what form is it used for fuel in the open-hearth furnace? Of what advantage is its use?

24. Name advantages of the open-hearth furnace over the Bessemer converter, and vice versa.

25. What advantage does a tilting open-hearth furnace have over the stationary kind?

26. Should duplex steel be cheaper or dearer than straight open-hearth steel? Explain your answer.

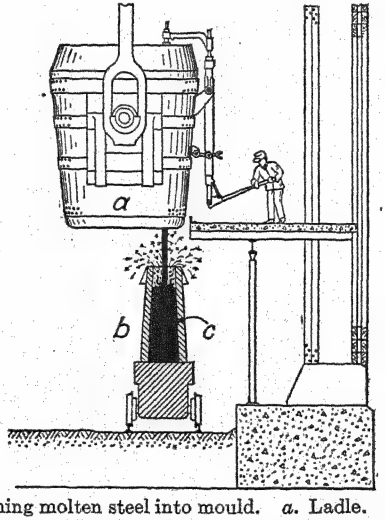

FIG. 188.—Teeming molten steel into mould. *a.* Ladle. *b.* Ingot mould. *c.* Ingot. (*Courtesy of Minnesota Steel Company.*)

ROLLING MILLS AND FORGING

Soaking Pits.—As the steel is tapped from the furnace, it is collected in large ladles and teemed into ingot moulds of suitable capacity for metal for railroad rails, structural members, or blooms for other

commercial forms (Fig. 188). While still white hot the ingots are stripped from the moulds and taken to the soaking pits, where they are kept at a high temperature until they are solid throughout and all the internal stresses relieved. The soaking pits are special, gas-fired furnaces located near the rolling mills for convenience (Fig. 190). They are generally constructed below the level of the floor to conserve the heat and to allow the ingots to be charged and discharged with a minimum amount of labor. The time required for soaking is from one to three hours, depending upon the size of the ingots and the nature of the steel.

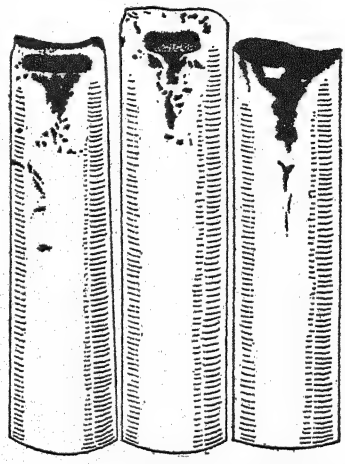

FIG. 189.—Ingots, showing pipe.

Rolling Mills.—From the soaking pits the ingots go directly to the rolling mills to be formed into rails, structural members, slabs, blooms, and other commercial forms. The rolling mills are of three general types: the two high, the three high, and the reversing (Fig. 192*a*, *b*). The two-high type is constructed with two rolls placed in a horizontal position similar to the rolls of a clothes wringer. As a rule, they are used only for small work that can be manipulated by hand. Rods, wire stock, light sheets, etc., are typical of the work done in these mills. Three-high mills have three horizontal rolls placed one above the other. The work

passes under the center roll in one direction and on the top in the opposite direction, thus saving time and energy required to bring it back to the starting point before another pass is made.

Three-high mills are used largely for finishing. Reversible mills are two high and differ from the other

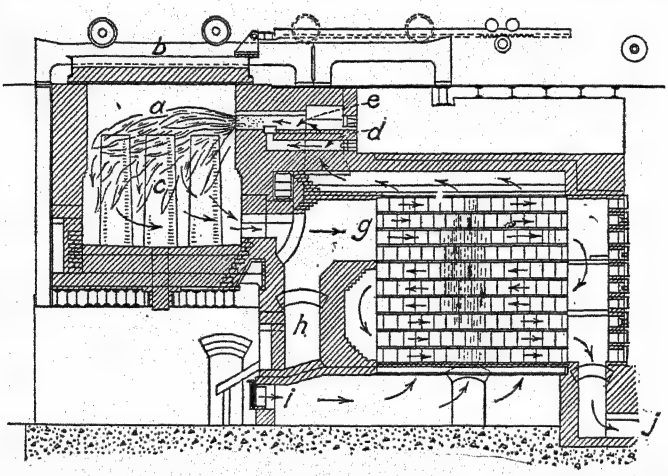

FIG. 190.—Soaking pit. *a*. Pit on furnace proper. *b*. Cover on door. *c*. Ingots. *d*. Gas flue. *e*. Air duct. *g*. Recuperative chambers. *h*. Slag pocket. *i*. Air intake. *j*. To stack. (*Courtesy of The Chapman-Stein Furnace Company.*)

two-high type in that the rolls are geared to revolve in either direction. As a rule, these mills are heavy blooming or roughing mills and are used in the first stages of rolling. In addition to the regular types there are mills for special rolling, of which the universal mill is a good example. This mill has vertical as well as horizontal rolls and reduces the edges of stock as well as the sides. The principal function of the vertical rolls, however, is to make the edges of the work

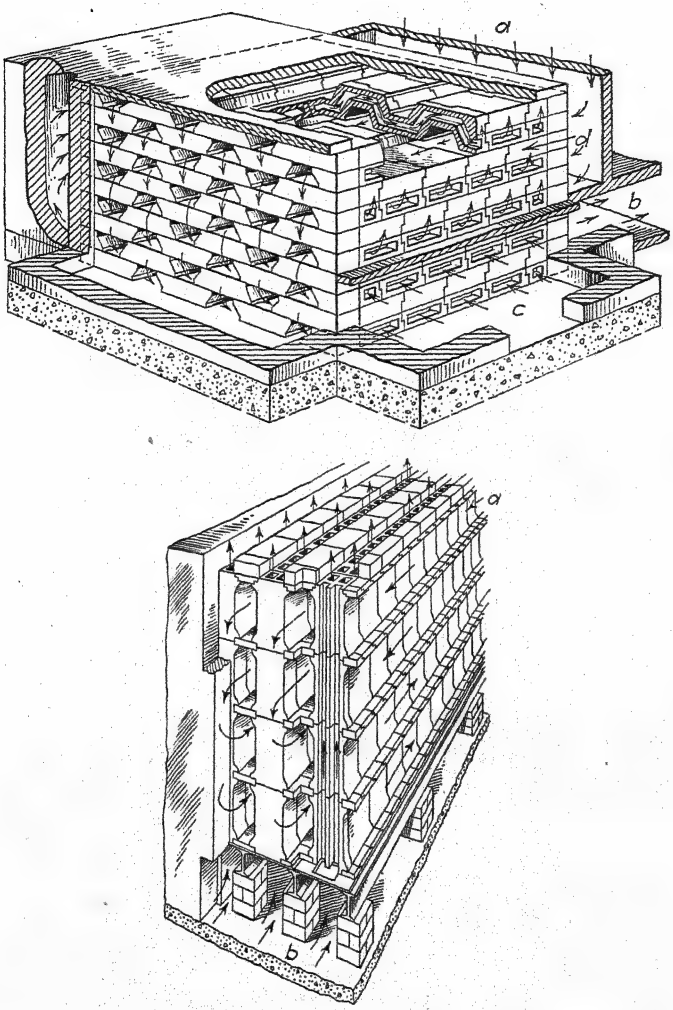

FIG. 191.—Recuperative systems. Top: Posnack system. (*Courtesy of E. R. Posnack.*) Bottom: Chapman-Stein system. (*Courtesy of The Chapman-Stein Furnace Company.*) *a.* Hot gases. *b.* Cooled gases, stock. *c.* Incoming cold air. *d.* Preheated air to furnace.

straight and true. In cases of mills used for very wide plates it is necessary to reinforce the regular rolls to keep them from springing. This is done with extra stiffening rolls installed above and below the

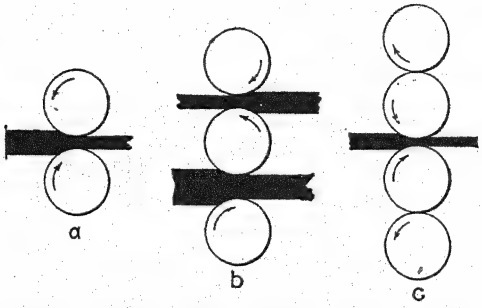

FIG. 192.—Types of rolls in mills. *a*. Two high. *b*. Three high. *c*. Two high reinforced.

regular rolls and revolved against them (Fig. 192*c*). For all kinds of work except flat pieces the rolls must be grooved or formed. As a rule, they have a series of grooves starting with a large size and gradually

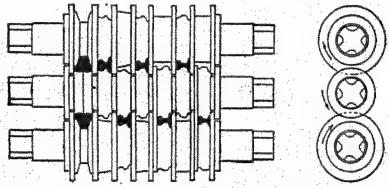

FIG. 193.—Formed rolls for railroad rails.

reducing until the finished size and shape are reached. Figure 193 will give an idea of some of the forms required for rolling a typical railroad rail.

The reduction of steel in each pass varies from the original according to the nature of the metal, its temperature, and the character of the rolls. A

standard railroad rail can be produced in about twenty-two passes and travels through the rolls sometimes at the rate of ten miles an hour. Some American mills produce over a mile of rail per hour for twenty-four hours. Rod mills have been developed which will produce rods at the rate of half a mile per minute, the rolls sometimes having a speed of 1,200 revolutions per minute. Water is generally thrown on the rolls in rolling larger work to keep them cool

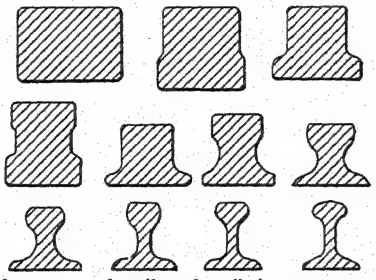

FIG. 194.—Development of railroad rail in process of rolling. (*After Stoughton.*)

and to assist in removing the scale (iron oxide). The steam generated causes a terrific explosion which loosens the scale and allows it to fall off. Sand and salt are sometimes used for the same purpose. Friction caused by the crushing of the molecules when rolling keeps the metal white hot until it is finished. If there is delay, however, the metal must go back to furnaces for reheating or be thrown in the scrap pile for remelting.

Often three-ply plate is produced in rolling mills. This generally consists of a sheet of hard manganese steel for the center and wrought iron for the outsides.

The pieces are heated separately to a welding heat and then put together and passed through rolls that weld them into a solid plate. This class of work is used for burglar-proof safes and in other places where both hardness and shock-resisting qualities are required. Special high-grade steel is sometimes produced by hot rolling the stock to approximate size and then drawing it cold through a die, reducing the diameter about one-sixteenth of an inch. Such steel has the commercial name of "cold-drawn steel." Rolls are generally made of special high-grade alloy steels or chilled cast iron.

Forging or Pressing.—It is evident that only work of uniform cross-section and reasonable length can be produced by rolling. As many forms other than these are required, means for their production must be provided. A large percentage of this class of work is obtained by casting, but this method is suitable only for cast iron and certain forms of steel.

As a rule, forging or pressing is used for odd shapes when high-grade malleable iron or steel is required. Forging in general is the process of hammering metal into form when white or red hot. Probably the most common example of this seen is in the village blacksmith's shop. The process is used, however, with machine hammers for the production of a large variety of articles in all manner of iron and steel industries. Among the more common machine hammers used are the steam and air hammers, the drop hammer, and the trip hammer. The steam hammer is the largest and more powerful of the three (Figs. 195,

197). They are often constructed to deliver a blow of thirty to fifty tons and even larger. But, if too large, they set up a terrific vibration which not only disturbs their own foundations but also damages the other machinery of the plant.

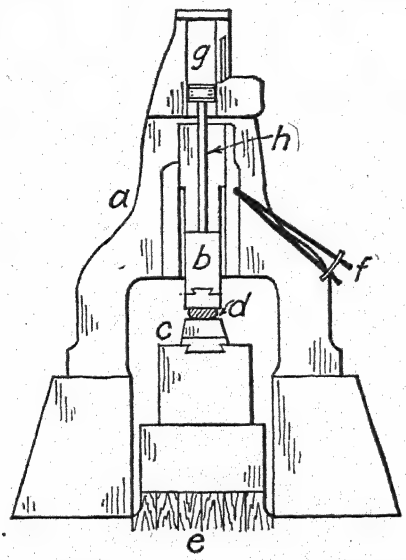

FIG. 195.—Steam hammer. *a.* Frame. *b.* Hammer. *c.* Anvil. *d.* Work. *e.* Wood foundation. *f.* Controls. *g.* Cylinder. *h.* Piston rod. (*Courtesy of Morgan Engineering Company.*)

Among the more conspicuous articles forged by the steam hammer are battleship guns, propeller shafts, heavy crank shafts, locomotive frames, car-wheel axles, and blooms of high-grade steel for saws and other tools. One advantage in forging steel for high-grade work is that the scale is loosened and removed more thoroughly than in rolling. Drop and trip hammers are used for smaller articles.

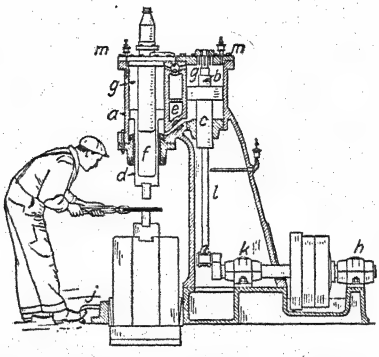

FIG. 196.—Power hammer. *a*. Housing. *b*. Piston. *c*. Connecting rod. *d*. Hammer. *e*. Port. *f*. Ram. *g*. Ram cylinder. *h*. Bearing. *j*. Treadle. *k*. Bearing. *l*. Frame. *m*. Ram cylinder head. (*Courtesy of Nazel Engineering and Machine Works.*)

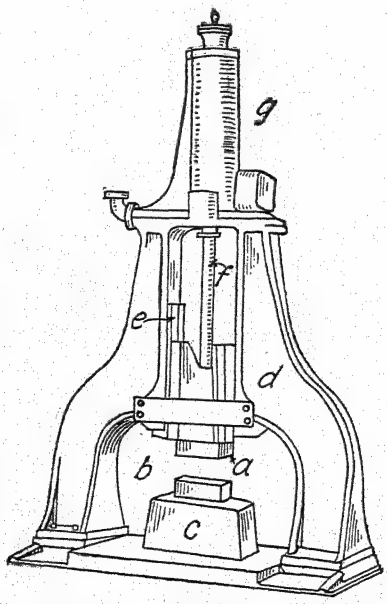

FIG. 197.—Power hammer. *a*. Hammer. *b*. Anvil. *c*. Anvil base. *d*. Frame. *e*. Guide. *f*. Piston. *g*. Cylinder. (*Courtesy of Nazel Engineering and Machine Works.*)

A great variety of articles is made by so-called "drop forging." This process differs from regular forging in that the work is hammered into dies instead of being shaped by the eye. Drop forging can be profitably used only when a large number of articles of the same shape and size are required, because of the expense of the dies. The process is extensively used for the production of automobile parts, locks, small fittings, etc.

Closely allied to drop forging is pressing, which differs from the former in that the work is pressed into form instead of being hammered. Presses for this work range in capacity from a few thousand pounds to 15,000 tons or more. They are of the continuous or intermittent types, that is, with the pressure applied continuously or intermittently. Heavy armor plate is an example of work formed by pressing. Thin sheet pressing is often done with the metal cold and is used extensively in the construction of railroad cars, automobile bodies, ornamental ceilings, etc. As a rule, forged steel is considered superior in quality to that produced by rolling, because the force is applied intermittently, and there is comparatively less sudden unit of change, resulting in giving the metal greater strength and elasticity. Pressing is also considered superior to rolling because it causes the metal to flow more uniformly throughout the piece.

Rolling-mill and Forging Terms

air hammer—A power hammer operated by compressed air.

armor plate—Metallic plates of steel used for protective covering for the vital parts of battleships, forts, etc.

bloom—The ingot of steel as it passes through the early rolls in the process of rolling. Also a mass of wrought iron as it leaves the squeezer.

blooming mill—The first mill to receive the ingot in the process of roughing.

boiler plate—Steel sheets or plates rolled for boiler or tank construction.

chilled cast iron—Castings of iron made in moulds or parts of moulds that are faced with iron or steel. The castings cool rapidly in these parts and so retain a larger percentage of carbon.

cogging mill—The first mill to receive the ingot with rolls cogged to facilitate gripping the steel.

cold saw—A saw for cutting cold metal.

cold-drawn steel—Steel rods finished by drawing them through a die to reduce their size and to give them better quality.

dies—Hard metal forms for receiving metal and shaping articles, under pressure.

flash—The thin extension of metal squeezed out between the parts of a die in drop forging.

forging—Shaping pieces of metal by hammering (generally when white or red hot).

hot saw—A saw for cutting hot metal.

hydraulic press—A powerful press operated by water power.

multiple-ply plate—Steel plates made up of thicknesses of other plates of steel or steel and wrought iron welded together.

pull-over mill—A two-high mill in which the work passes through only one way; it must be pulled back to the starting point before passing through again.

ragged rolls—Rolls with rough surfaces to facilitate the gripping of the steel in the first stages of rolling as distinguished from the smooth-finishing rolls.

reversing mills—Rolling mills in which the direction of the rolls reverses to allow the work to pass through in either direction.

roll table—The platform or table upon which the work is handled and fed to the rolls.

roughing mill—Same as cogging mill.

screw-down mechanism—That mechanism on a mill for lowering and raising the rolls to accommodate the distance between them to the requirements of the article being rolled.

steam hammer—A power hammer operated by steam.

three-high mills—A rolling mill with three rolls one above the other.

train of rolls—A series of mills, one after the other, each successive mill approaching more nearly the size of the finished piece.

transfer table—A table connected with rolling mills for transferring work from one mill to the other laterally.

trip hammer—A hammer operated by a tripping device or release which allows the hammer to drop.

two-high mill—A rolling mill with one pair of rolls one above the other.

Rolling, Forging, and Pressing Questions

Group I

1. Give a brief description of a soaking pit.

2. Mention two reasons why soaking pits are located below the floor level.

3. What determines the time required for ingots in the soaking pits?

4. What determines the amount of reduction that steel should have at one pass through the rolls?

5. What types of rolls receive the ingots first from the soaking pits?

6. Why is water thrown on to the rolls when they are in action? Give two reasons.

7. Under what conditions are extra stiffening rolls used with a rolling mill?

8. Name several articles produced by rolling.

9. How is multiple-ply plate produced? Mention some of its qualities and also some of its uses.

10. Explain briefly how cold-drawn steel is produced.

11. Mention some of the more common articles made under the power hammer.

12. Give the typical uses of the two-high and three-high mills.

13. Why is forged or pressed steel generally considered superior to rolled steel?

14. Of what materials are rolls generally made?

15. What is the objection to very heavy steam hammers?

Group II

16. Why must rolled work generally be of uniform cross-section?

17. Why are railroad rails generally rolled in long sections and cut to proper lengths afterward?

18. Why is it necessary to pass the work through the rolls so many times?

19. What might happen to a rail if a gas bubble were to remain in the ingot when it solidified?

20. Explain what is meant by the terms "hot" saw and "cold" saw.

21. Explain the difference between a power hammer and a trip hammer.

22. Why is die making expensive?

23. Mention other methods of forming metal objects besides casting, rolling, forging, and pressing.

24. Explain why steel remains hot when rapidly rolled or otherwise rapidly worked.

25. We sometimes see a thin extension of metal (flash or fin) on a piece that has been drop forged. Explain why this is.

26. Mention some of the qualities that steel for railroad rails must possess.

27. How should structural steel differ in quality from steel for cutlery?

28. What might happen if the work was passed through the rolls too rapidly; too slowly?

29. What is the purpose of the screw-down mechanism on a rolling mill?

30. How could we determine by the appearance of an article whether it had been produced by casting or by forging?

31. What might happen if the rolls were made too small in diameter; too large?

32. How does the diameter of rolls affect their speed?

33. What is meant by the term "cross-section"?

34. Why must pull-over mills be confined to smaller work?

35. What are some of the more important points that must be considered in designing a rolling mill?

36. What are some of the points to consider in locating rolling mills in a steel plant?

37. Compare rolling steel with forging and pressing as to time required.

WROUGHT IRON

Early Production.—Wrought iron is the purest commercial iron known and was the earliest form to be produced. As has been noted, it was probably first made in a crude pit furnace dug in the side of a hill facing the prevailing wind. A quantity of rich ore and charcoal was charged into the pit, and the fire lighted, and, after a blast of natural wind, probably augmented by a bellows, there resulted a pasty mass of iron and slag which could be hammered into form. For centuries the development of the iron industry was slow, and the metal produced was used only for weapons of warfare and trinkets for the rich. Yet in spite of crude methods the ancients produced iron and steel of superior quality, and the metals used in the famous Damascus and Toledo sword blades and in the sacred pillar of India as well as elsewhere have never been surpassed.

Development.—The first real wrought-iron furnace, the forerunner of our present hand-puddling furnace, was invented by Henry Cort about 1790 and improved by Joseph Hall about 1830. Although it has been modified considerably in form and size, it has remained practically the same in principle as when first invented.

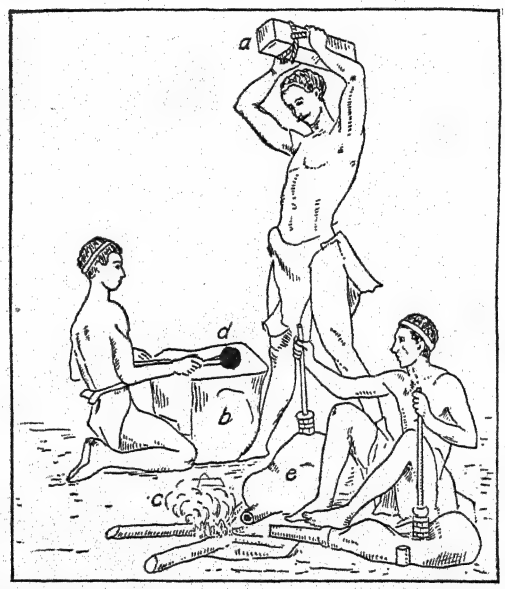

FIG. 198.—Ancient forge and power hammer. *a.* Hammer. *b.* Anvil. *c.* Fire. *d.* Work. *e.* Bellows. (*Courtesy of Standard Oil Company of New York.*)

For many years the product of this furnace was the most important of the iron group, but discoveries of improved methods of steel making in the last century have revolutionized the whole iron industry, and mild steel now largely takes the place of wrought iron, except in places where severe shock must be withstood and where a slow corroding metal is required.

Hand Puddling.—Modern hand-puddling furnaces are of two general types, single and double, and range in capacity from 500 to 1,500 pounds per heat. They are rectangular in form and are usually constructed of reinforced masonwork lined with fire bricks (Fig. 201). A shallow, basin-like hearth occupies the central portion. At one end is a grate where

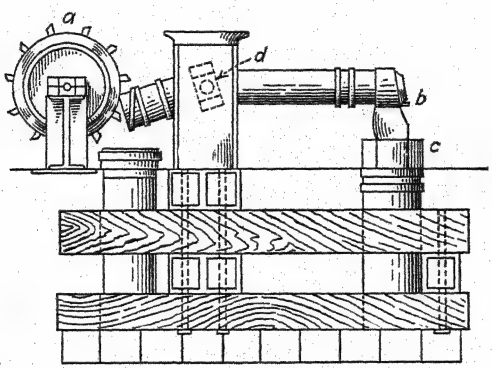

FIG. 199.—Trip hammer. *a.* Tripper. *b.* Hammer. *c.* Anvil. *d.* Fulcrum. (*Courtesy of Frederick A. Stokes Company.*)

soft coal is burned to furnish the heat, and at the other end are a neck and stack to convey away the waste gases. A low wall, or bridge, separates the grate from the hearth and directs the flames to the roof, from which they are deflected to the surface of the bath. A lower wall called the "breast," or "altar," separates the opposite side of the hearth from the neck. The roof is low and curves downward toward the neck, thus concentrating the heat on the bath where it is needed for melting and refining the metal. A charging and discharging door is constructed in one side at the edge of the hearth, and through a

small opening in this door the rabble is worked in puddling. The bottom of the hearth is constructed of iron plates about an inch and a half thick and is exposed to the air on the under side to allow for cooling. This precaution is necessary to prevent the intense heat from destroying the lining and to ensure a hard, smooth-working hearth bottom. Hollow castings, through which water or air is circulated, are embedded

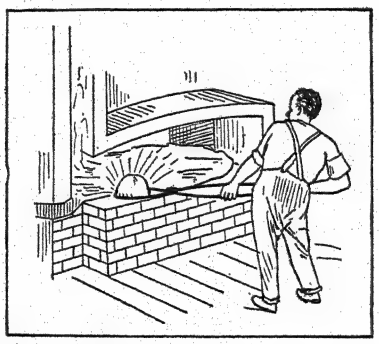

FIG. 200.—Early hand-puddling furnace. (*Courtesy of Reading Iron Company.*)

in both the bridge and the breast to counteract the heat in these parts.

The charge generally consists of special high-grade pig iron. Before it is introduced, however, the hearth is lined with iron oxide in the form of rich ore and mill scale or puddle cinder reduced to a molten state. The operator (puddler) moves the pigs about with an iron bar (rabble), to expose all parts evenly to the reducing flames so that the melting will take place as uniformly as possible. The puddler also stirs, or puddles, the mass or batch as the process continues to bring all parts of the iron into contact with the oxidizing agents

and to prevent it from settling and sticking to the bottom of the hearth. Silicon, carbon, manganese, sulphur, and phosphorus are burned off, and, after a time, small balls of iron begin to show through the surrounding slag. The batch now settles down into a pasty condition ("comes to nature," as it is called), on account of the rise in temperature of the fusing point of the iron, and is ready to be removed to the

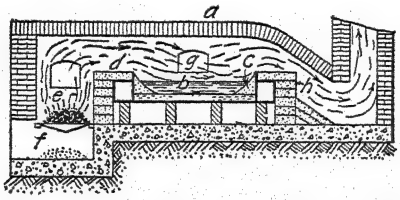

FIG. 201.—Modern hand-puddling furnace. *a*. Roof. *b*. Bath or charge. *c*. Hearth lining. *d*. Bridge. *e*. Furnace. *f*. Ash pit. *g*. Charging door. *h*. Altar. (*After Pulver*.)

squeezer. Fresh pig is charged in, and the process is repeated without waste of time and fuel.

About one ton of coal is required to produce one ton of iron. Much waste heat escapes up the chimney. This is sometimes utilized, however, to generate steam or to increase the temperature of reheating furnaces.

Squeezing Process.—The squeezer generally used is of the rotary, or coffee-mill, type. It consists of a wide rigid steel cylinder with teeth around its circumference (Figs. 202, 203). This cylinder revolves horizontally in a spiral housing which has corresponding teeth in its inner surface. The housing encircles about three-fourths of the circumference of the drum, leaving two openings of unequal size. The spongy

ball of iron, white hot and dripping with slag, is inserted into the larger opening and is gripped by the

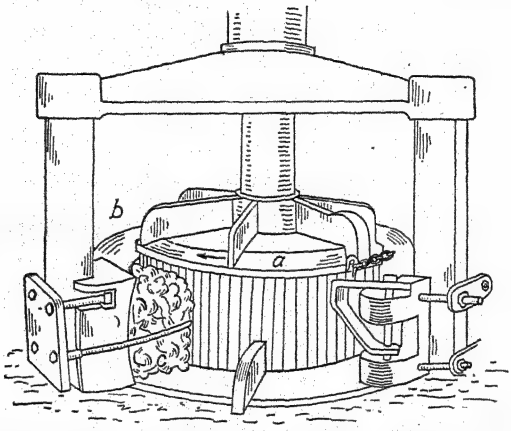

FIG. 202.—Mechanical squeezer. *a*. Toothed cylinder. *b*. Housing. *c*. Wrought-iron ball. (*Courtesy of Reading Iron Company.*)

teeth of the wheel and rolled and kneaded around the spiral surface, like a ball of putty being rolled between

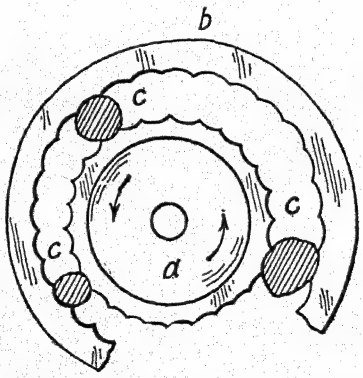

FIG. 203.—Cross-section of mechanical squeezer. *a*. Toothed cylinder. *b*. Housing. *c*. Wrought-iron ball.

the hands, and finally comes out of the small opening in the form of a rough cylinder called a "bloom."

Because of its lower fusing point, the slag remains molten and is largely pressed out in the squeezing process, while that which remains is distributed evenly among the iron fibers. The presence of the slag among the iron fibers enables the metal to resist rust. The bloom is taken to the bar mill (muck rolls, Fig. 204) and rolled into muck bars (also called "puddle bars"), which are cut into short lengths, piled and

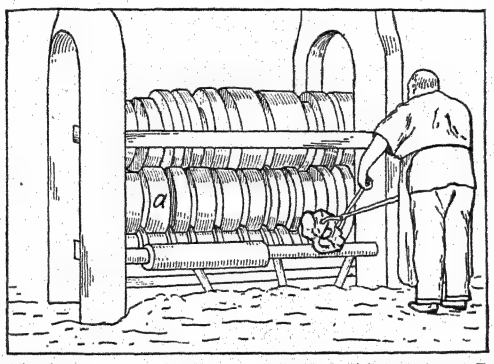

FIG. 204.—Muck rolls. *a*. Rolls. *b*. Work. (*Courtesy of Reading Iron Company.*)

wired together, reheated to welding heat, and rerolled into merchant bars or other commercial forms (Fig. 205). If a still better quality of iron is required, the cutting, reheating, and rerolling processes are repeated.

Up to a few years ago wrought iron was produced in the hand-puddling furnace exclusively. Increasing difficulty, however, in securing a supply of efficient hand puddlers, as well as changing conditions in other respects that tend to make the product more expensive, aroused producers to attempt to develop a furnace that

could be operated mechanically and could turn out iron on a large scale at less cost.

Mechanical Puddling.—Several mechanical puddlers have been developed that have met with more or less success, although none of them seems to be running at the present time. In each case the objective seems to have been to produce a machine that would mix and stir the metal in place of that laborious task con-

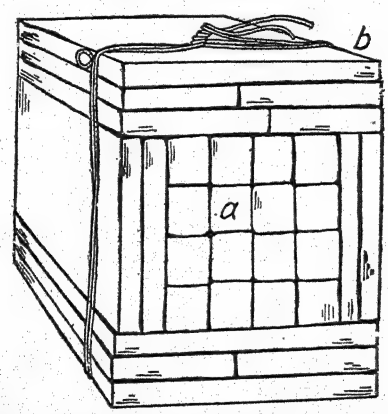

FIG. 205.—Bundle of wrought-iron pieces ready for reheating and welding. *a*. Pieces of wrought iron. *b*. Wire band.

nected with the hand-puddling process. Among furnaces developed for the purpose were the Danks puddler, which ran from 1868 to 1885, the Ford, the Ely, the Hibbard, and the Roe. The latter was used up to 1938. A brief description of the Roe furnace as typical of the rest will suffice at this time. This furnace consists of a rectangular steel shell about 25 feet long, 12 feet wide, and 7 feet high inside measure, with an elliptical bottom, or hearth, turned up on either end like the front of a toboggan (Fig. 206). The

top is lined with common fire bricks, and the sides and bottom are lined with magnesite bricks which are cemented in with fluid cinder, the bottom lining being supported on a series of rectangular water pipes for protecting the bricks. The whole machine is mounted on two hollow trunnions centrally located, one on either side, which open into the interior and admit the

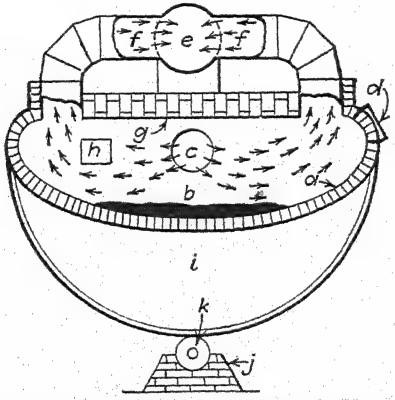

FIG. 206.—Mechanical puddler. *a.* Fire-brick lining. *b.* Bath. *c.* Gas intake. *d.* Discharging door. *e.* Waste gas flue to regenerative chambers. *f.* Gas flues. *g.* Roof. *h.* Charging door. *i.* Rocker. *j.* Foundation. *k.* Pinion.

gas and air for combustion. (The waste gases escape through ducts in the top near both ends and are led away to the recuperative chambers.) The trunnions are supported on roller bearings and are so adjusted that the furnace can be rocked back and forth through an angle of 120 degrees. A discharging door, suspended from above, occupies all of one end of the hearth and is operated by a hydraulic cylinder working underneath. An opening is located in one side near the opposite end for charging. Projecting below the

outside edges of the hearth are rockers having circular lower edges provided with gear teeth that mesh with pinions which transmit power for the rocking motion.

Before the charge is introduced, gas and air are admitted and burned to raise the temperature of the interior to the required degree. Then molten oxide of iron is poured in, congeals, and forms a working bottom. This is followed by melted puddle cinder which seals up all crevices and makes the hearth liquid-tight. The charge proper consists of about three tons of molten pig directly from the mixer or blast furnace. As the furnace rocks, the metal flows back and forth over the hearth, tumbling and rolling up on itself at the ends like waves on the beach. This motion thoroughly mixes it and exposes all parts evenly to the oxidizing agents. The rocking movement has the same effect on the iron in this furnace that hand puddling has in the ordinary furnace. Additional iron oxide in the form of mill scale is introduced immediately after the iron with a long spoonlike scoop that distributes it evenly across the whole bath. The rate of motion of the furnace is regulated to meet the needs of the iron as the process continues, and the flow of gas and air is checked or increased to hold the temperature to the proper degree for burning off the impurities. After about an hour the iron begins to roll up into a spongelike, pasty ball similar in nature to that in the hand furnace and is ready to be removed. The furnace is now tilted, the door opened, and the spongy mass, resembling in form a huge, oblong loaf of bread, rolls

out on to a wall crane and is conveyed away to the squeezer.

Mechanical Squeezing.—The squeezing is done in a powerful hydraulic press that has both horizontal and vertical jaw movements, ensuring an even distribution of the pressure on all sides. Because of its lower fusing point the slag remains in a liquid state longer

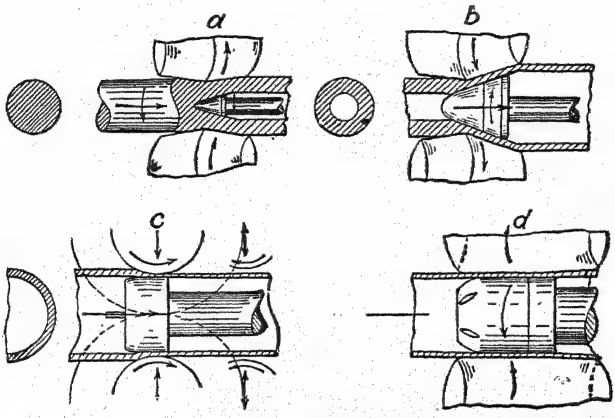

FIG. 207.—Seamless pipe by automatic process. *a.* Piercing machine. *b.* Second piercing or expanding mill. *c.* Plug or rolling mill. *d.* Reeling machines. (*Courtesy of Oil and Gas Journal.*)

than the iron and easily runs out through holes in the faces of the jaws. That which remains is distributed among the iron fibers. It is the presence of the slag throughout the iron that prevents it from rusting. The bloom is next reheated and cut into slabs of convenient size for handling, which in turn are again reheated, muck rolled, and otherwise treated in the same manner as hand-puddled iron. It is claimed that better results, from an economical and metal-

lurgical standpoint, would be obtained if blooms of suitable size for direct rolling to commercial forms could be pressed and rolled direct. This would do away with the cutting and piling processes which sometimes leave the iron laminated and defective. Up to the present time, however, no suitable equipment has been installed to accomplish this on a commercial scale.

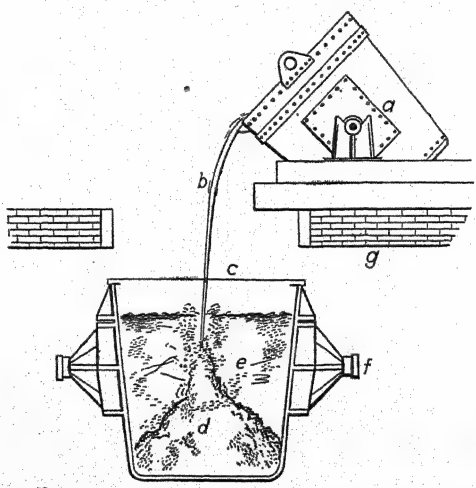

FIG. 207*a*.—Byers process for wrought iron production. *a*. Pure iron ladle. *b*. Molten pure iron. *c*. Wrought iron ladle. *d*. Slag and iron mixture. *e*. Molten slag. *f*. Trunnion or lug. *g*. Platform. (*Courtesy of A. M. Byers Company.*)

Comparing the mechanical puddler with the hand-puddling furnace, we find that while the time per heat required is practically the same for both, the output of the mechanical puddler working under normal conditions is 1,000 tons per month while that of the best double hand-puddling furnace is only 100 tons per

month, or only one-tenth as much. There has been some question as to the possibility of producing iron of as good quality in mechanical puddlers as in hand furnaces, but experiments carried on by the Bureau of Standards have shown this to be possible, provided that proper raw materials are used for the charge and that the furnace is constructed and operated on scientific principles.

Byers Wrought-iron Process.—Up to 1915, comparatively little attention was given to the actual composition of wrought iron. Before that time greater stress was laid on processes for its production. In that year, however, exhaustive study of the subject was begun. Hundreds of samples of wrought iron, new and old, were analyzed and studied, with the result that the information gained formed the basis for an entirely new process of production of the metal (Fig. 207*a*), which was called the "Aston" process, after the man who made the discovery. In this process molten iron is refined in an ordinary type of refining furnace, as the Bessemer converter, at a temperature of about 2800°F. It is then poured into a bath of purified, molten silica slag at a temperature of about 2300°F. The sudden lowering of the temperature of the refined metal causes tiny explosions which disseminate it uniformly throughout the slag. The result is a mass of practically pure iron consisting of globules about the size of a pea coated with slag. The mass while still in a plastic state is passed through a powerful squeezer where a large part of the slag is removed and the remainder evenly distributed. The iron is then

cut, reheated, rerolled, and otherwise treated as puddling-furnace wrought iron. A single charge consists of from three to four tons, and the amount of slag retained is about 5 per cent in bulk of that of the iron.

Although the process is new, it has passed beyond the purely experimental stage, and already facilities are established for the production of this brand of wrought iron on a large commercial scale.

The principal qualities of wrought iron are malleability, toughness, resistance to shock, resistance to oxidation (rust), and adaptability for welding. Its principal uses are for stay bolts, rivets, water and steam pipes, tubing, chains, raw material for crucible steel, and blacksmith's supplies.

The raw material from which wrought iron is made consists of pig iron, iron oxide, and silica. The pig iron is melted continuously in cupolas, tapped into ladles, where it receives a special desulphurizing treatment, and is then conveyed to a Bessemer converter, where it is purified to the highly refined state required for the base metal in quality wrought iron. It is then carried by crane and ladle car to the processing platform and poured into the ladle of the processing machine.

In the meantime an exact iron-silicate slag, formed by melting together iron oxide and certain siliceous materials in an open-hearth furnace, is poured into a ladle, which is placed on a ladle car so that it can be moved to the different stations representing stages in the process. The first station is directly below the processing machine.

Next follows the key operation of the process—that of refined metal disintegration and slag incorporation. The molten refined iron is poured at a predetermined rate into

the ladle containing the molten slag. The processing machine automatically oscillates as well as moves forward and backward, ensuring a uniform distribution of the refined metal into the slag.

Since the temperature of the slag is maintained at a few hundred degrees lower than the "freezing point" of the refined iron, the latter is continuously and rapidly solidified. This rapid solidification liberates the gases dissolved in the molten metal with such force that the metal is shattered into small fragments, which settle to the bottom of the slag ladle. Because of the welding temperature and fluxing action of the siliceous slag, these fragments cohere to form a sponge-like ball of iron impregnated with the liquid slag weighing from 6,000 to 8,000 pounds.[1]

Wrought-iron Terms

balling—Bunching wrought iron in the furnace into balls of suitable size to take to the squeezer.

bloom—A mass of wrought iron after it has passed through the squeezer and had the slag removed.

bulldog—Roasted puddle cinder or slag.

come to nature—The charge settling down into a pasty mass after boiling.

fettling—The inner lining of the hearth.

forge iron—Pig iron used for the charge of a puddling furnace.

mechanical puddler—A wrought-iron (rocking) furnace in which the puddling is done by mechanical motion instead of by hand.

merchant bar—Wrought-iron bars produced by reheating, welding, and rerolling muck bars.

mill scale—Iron-oxide scale which forms on the surface of iron and steel when worked hot, especially when rolling.

[1] Courtesy of A. M. Byers Company.

muck bars—Rough bars of wrought iron as they come from the first set of rolls, the muck rolls.

muck rolls—The first set of rolls through which wrought iron is passed as it comes from the squeezer.

puddle—The batch, or mass, of molten iron in the puddling furnace.

puddle bars—The same as muck bars.

puddle cinder—The slag from the batch of a puddling furnace.

puddle rolls—The same as muck rolls.

puddler—The operator who works the puddling furnace.

rabble—An iron bar used for puddling the batch in a puddling furnace.

scrap bar—The uneven ends of the muck bars.

shingling—Reducing wrought-iron balls under a hammer to remove the slag and weld the iron together. (Used in England in place of squeezing.)

shotting—The quenching of molten iron in molten slag to produce wrought iron.

skelp iron—Wrought iron rolled into flat bars suitable for making pipe.

squeezer—The mechanical device for squeezing a part of the slag from the wrought-iron ball and thoroughly mixing the remainder among the fibers.

Wrought-iron Questions

Group I

1. Who invented the puddling furnace for wrought iron? About what year was this? By whom was it improved, and about what year?

2. What is the size of a typical hand-puddling wrought-iron furnace?

3. Of how great relative importance was wrought iron in early times?

4. Mention articles of high-grade iron or steel that existed in very early times.

5. Name the general parts of a modern hand-puddling furnace, and mention some of the materials out of which they are constructed.

6. Why are wrought-iron furnaces constructed with iron plates for the hearth bottom?

7. Name the materials of a charge for the wrought-iron furnace, and give the purpose of each.

8. Why does the operator stir or rabble the molten batch?

9. Explain what is meant by coming to nature.

10. What is the purpose of the squeezer?

11. Explain how muck bars are treated to produce merchant bars.

12. What are some of the factors that induced producers to look for other means of making wrought iron than hand puddling?

13. Explain the action of the mechanical puddling furnace.

14. What makes wrought iron less apt to rust than common steel?

15. Why does slag remain molten longer than iron?

16. Explain why the batch becomes pasty without the temperature's being lowered.

17. What occurs when purified molten iron is poured into molten slag? Explain why this happens.

Group II

18. Why is the wrought-iron furnace called a puddling furnace?

19. Why is the furnace called a "reverberatory" furnace?

20. Explain what is meant by a double wrought-iron furnace.

21. What general elements does pig iron contain that must be removed to produce wrought iron?

22. Why is it necessary to send the iron through the squeezer?

23. Why is the housing of the squeezer constructed in the form of a spiral?

24. Why is the name "wrought" applied to this particular grade of iron?

25. Name advantages of the mechanical puddler over the hand-puddling furnace.

26. How do the Bessemer and open-hearth furnaces assist in the production of Aston-process wrought iron?

27. Name one special quality in which Bessemer steel is inferior to wrought iron.

28. Explain why the trunnions of the mechanical puddler must be centrally located.

29. Explain why wrought iron is especially good for water pipes.

30. Why is wrought iron especially good for heavy chains?

31. How ought the invention of stainless steel to affect the wrought-iron industry?

CHARCOAL IRON[1]

The charcoal knobbling furnace, forge, or bloomery fire, as it is variously called, is almost identical with its prototype, the Catalan forge, used in the Spanish province of Catalonia in the thirteenth century. This furnace, in which it was possible to produce 140 pounds of iron in five hours, was an advance over earlier types and probably represented the high water mark of efficiency in the production of wrought iron direct from the ore in the Middle Ages.

These furnaces were of stone with an open front about 3 feet high by 2 feet wide, the depth being slightly greater. Air was supplied by water-power blast that entered the furnace through a tuyere, usually in the back wall. After lighting such a furnace, alternate layers of crushed ore and charcoal were charged, and by successive meltings and the expenditure of much fuel and labor a small lump of more or less pure sponge iron resulted which was subsequently forged into desired shapes by the smith.

After the development of the blast furnace, less and less ore was sunk in charcoal bloomery fires because it was

[1] Courtesy of George D. Lain, superintendent, Reading Iron Company.

found to be more economical and satisfactory to reduce ore in the blast furnace and subsequently refine the pig in charcoal furnaces.

The charcoal furnace of the present is built up of cast-iron plates and consists of a shell (the oven), a lining (side plates) bolted to the oven, and a hearth of heavy plates wedged tightly against the side plates (Fig. 208).

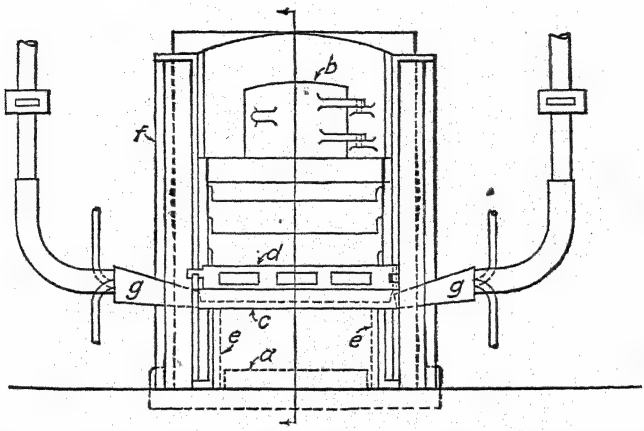

FIG. 208.—Charcoal iron furnace. *a*. Bottom. *b*. Door. *c*. Foreplate. *d*. Working gate. *e*. Tuyere plates. *f*. Side plates. *g*. Tuyeres. (*Courtesy of Reading Iron Company.*)

A shelf, the foreplate, projects in front of the oven to receive the lump of iron as it is drawn from the hearth. The opening in the front through which the furnace is charged and worked is approximately thirty inches square.

Blast is supplied through one or two water-cooled tuyeres which project into the fireplace above the hearth. The pitch of the tuyere and its inclination toward the front of the fire, the position of the hearth plates, and the vertical distance from the hearth to the tuyere all have an important bearing on the operation of the furnace, which is extremely sensitive to changes in angles and dimensions.

After lighting a furnace and building up a bed of incandescent charcoal, alternate layers of metal and charcoal are charged. The forge man stands directly in front of the furnace and with bar and hook compacts the charge and yet keeps it open to the blast.

As the metal reaches the blast zone a portion of it and practically all of the impurities are oxidized into a highly basic slag. As a result of the oxidation and the violent reaction between the fluid slag and the molten charge, the latter is converted into particles of practically pure iron which aggregate in the hearth and remain in a plastic condition because of the higher melting point possessed by the iron.

At the end of thirty-five minutes, all of the charge has been melted and has "come to nature" on the hearth in an egg-shaped lump which after "shingling" (hammering) under a power hammer is reheated and rolled into bars.

The charge of today consists of from 300 to 350 pounds of selected light material, free from alloys. Approximately 800 pounds of charcoal are required per gross ton blooms produced, and the loss in sinking a charge varies from 8 to 10 per cent.

Two men operate one of the furnaces alternately and together produce roughly 1¾ gross tons of charcoal iron per day.

CEMENTATION STEEL

Equipment and Operation.—Formerly a high grade of cutlery steel was produced in the old countries by the so-called "cementation process." Because of its cost of production, however, it has been largely superseded by the crucible and electric furnaces. It was never used to any extent in this country.

The typical cementation-steel furnace consists of a superstructure of masonwork which acts as a stack to convey away the products of combustion and to prevent the loss of heat by radiation (Fig. 209). The real furnace is located within this stack and consists of an oblong fire-brick structure with several small chimneys of its own.

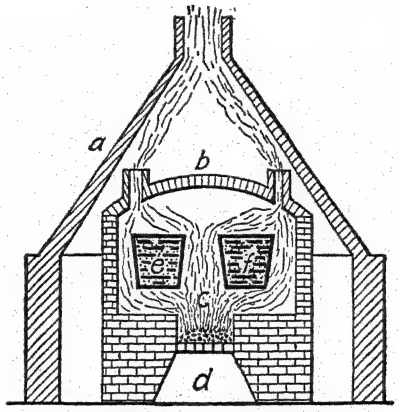

FIG. 209.—Cementation-steel furnace. *a*. Outer stack. *b*. Furnace *c*. Fire. *d*. Ash pit. *e*. Stone pots. *f*. Charge.

The charge consists of from 10 to 30 tons of flat wrought-iron bars about half an inch thick. These bars are packed in layers in powdered charcoal in air-tight stone boxes and subjected to a temperature of from 1200 to 1300°F. (a cherry-red heat). They are allowed to remain in this condition for from seven to eleven days, during which time the carbon permeates the bars, converting them into steel. Another seven days are allowed for cooling.

The product of the cementation furnace is called "blister steel" because of the blister-like scales (slag)

that form on its surface during the process. If higher grade steel is desired, blister bars are cut, piled, and forged down. It is then known as "single-shear" steel. If a still finer grade is desired, the process is repeated, and the product is known as "double-shear steel." In recent years, however, the more common practice of refining blister steel is to remelt it in the crucible furnace.

CRUCIBLE STEEL

Historical.—For many years practically all high-grade steels produced in this country were made in the crucible furnace. But just as cementation steel was superseded by crucible steel, so the latter is rapidly being replaced by electric steel.

The crucible-steel process was introduced by Huntzman, an Englishman, about 1740. He was experimenting more with the idea of discovering a method of distributing carbon evenly through cementation steel than of producing a new steel-making process. His experiments were so successful, however, that the crucible process soon became established as the leading method for making high-grade steel and has held its own up to the time of the advent of the electric furnace.

Modern Crucible Steel.—The modern crucible furnace is a masonwork structure with the furnace proper below the level of the floor (Fig. 210). A grate fire or other equipment furnishes the heat, and a stack conveys away the waste gases. At the top, or floor level, are from two to six openings, or melting

holes, through which the crucibles are lowered. The crucibles themselves are strong, potlike vessels of refractory materials such as mixtures of fire clay, graphite, or Carborundum. They are usually 10 inches in diameter and 18 inches high and have a capacity of about 100 pounds. The charge generally consists of wrought iron or scrap steel, or a mixture of the two, and a definite amount of charcoal. Other elements are added to modify the quality of the steel as may

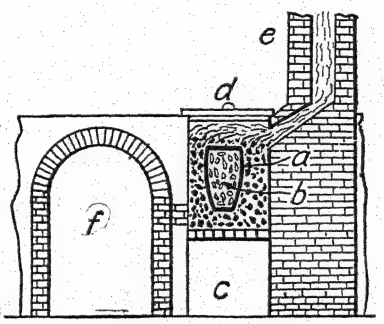

FIG. 210.—Crucible-steel furnace. *a.* Crucible. *b.* Charge. *c.* Ash pit. *d.* Melting hole. *e.* Stack. *f.* Cellar.

be desired. The charcoal is charged at the top of the other materials so that the carbon will permeate to all parts of the molten metal evenly as it settles down. The crucibles are now covered and lowered down into the furnace where they are allowed to remain under intense heat for three or four hours. During this time the metal is melted and refined into steel. After the steeling process proper, the crucibles are allowed to remain in the furnace for about forty-five minutes until the boiling ceases. This is known as the "killing process" and indicates that the carbon has been absorbed

and the gases expelled. The crucibles are now lifted out by the operator (the puller-out, Fig. 211), and the molten steel poured into ingot moulds of suitable size (generally about 2 by 4 inches by 2 feet long). Care must be exercised in pouring not to allow the metal to touch the sides of the moulds and to skim off the slag, or the quality of the metal will be affected.

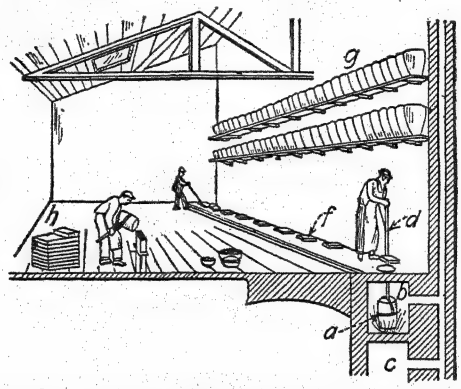

FIG. 211.—Crucible-steel melting house. *a*. Crucible. *b*. Furnaces. *c*. Ash pit. *d*. Tongs. *f*. Melting holes. *g*. Extra crucibles. *h*. Ingots of steel. (*After Stoughton.*)

Crucible steel is used for high-grade cutlery and other high-grade tools, for surgical instruments, files, and other articles where a superior quality of steel is required.

ELECTRIC STEEL

Historical.—Just as in other branches of industry, electricity has invaded the field of steel making, especially for high-grade steels. In fact, the electric-steel furnace has practically superseded the crucible furnace for high-grade steel making. Siemens of open-

hearth fame was the first to take out a patent for the manufacture of steel by electricity. This was in the year 1878. Siemens' furnace consisted of a crucible of refractory material with a vertical electrode suspended in the top and an iron electrode passing through the bottom. An arc struck between these electrodes furnished heat for melting and refining. In 1885 Farranti, an Italian, succeeded in devising a furnace upon the principle of induction. Other attempts were also made to use electricity for steel making, but only a few of them deserve special mention.

Héroult Furnace.—Among the more important furnaces so far developed are the Héroult, the Girod, and the Stassano, all of which are of the arc type. The Héroult furnace was invented by Dr. Héroult of France and came out early in the present century. It is the simplest type and the one most extensively used in the United States and in some foreign countries. These furnaces vary in size from two to seventy-five tons capacity and more, those ranging from five to fifteen tons being the most common. They consist of a steel-plate shell nearly rectangular or circular in form lined with refractory materials. The bottom of the interior is occupied by a shallow, dishlike hearth with a projecting spout at one edge for pouring (Fig. 212). In the roof are three openings through which large, upright carbon electrodes are lowered to supply the current. The hearth is lined with highly refractory material (generally magnesite bricks), and the roof with silica bricks because

of their greater strength. The electrodes are generally circular carbon rods and are lowered into the furnace by a screw-down mechanism as they burn off. The whole structure is mounted on rollers, or pinions, and can be tilted for pouring.

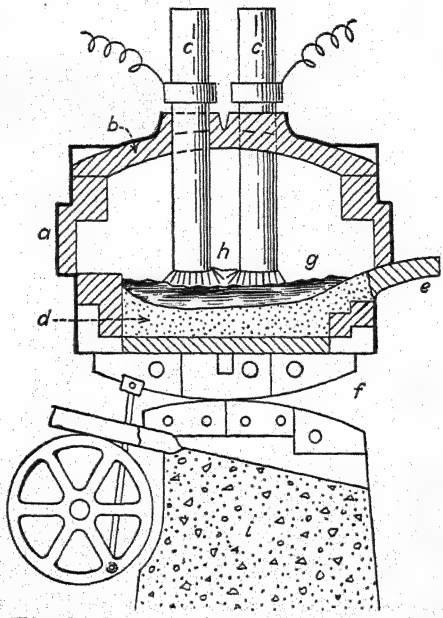

FIG. 212.—Héroult electric-steel furnace. *a.* Steel shell. *b.* Refractory lining. *c.* Carbon electrodes. *d.* Hearth. *e.* Spout. *f.* Rocker. *g.* Bath. *h.* Arc. *i.* Concrete foundation. (*After Stoughton.*)

The charge can be of either molten or cold materials to suit the convenience of the plant. In many plants, however, there are no other facilities for melting except in the furnace itself. High-grade scrap steel is generally used for the bulk of the charge when a high-grade steel is desired. (At present a large amount of scrap for high-grade electric steel is obtained from

automobile plants.) Before the charge is placed, the hearth is lined with dolomite and sintered to ensure a tight-working bottom. The materials of the charge are now weighed and introduced, and the carbons lowered. An arc is struck between the poles, and the current passes through the bath, melting and refining the metal. Lime is introduced to form a protecting slag covering, and alloying elements are added as needed. At the end of the heat the furnace is tilted, and the molten steel is poured into ladles and teemed into ingot moulds. The time required for a heat is from five to twelve hours, depending upon the nature of the steel desired and the size of the furnace.

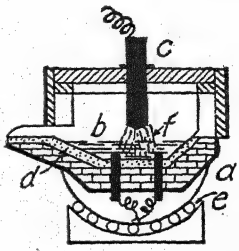

FIG. 213.—Girod electric-steel furnace. *a.* Steel shell. *b.* Bath. *c.* Carbon electrode. *d.* Hearth lining. *e.* Rollers. *f.* Arc. (*After Stoughton.*)

A large tonnage of steel is superrefined in this country in the Héroult furnace. In the process, steel produced in the open-hearth furnace or by a combination of the open-hearth and Bessemer furnaces is further refined in the electric furnace. Hence we have the so-called "duplex" and "triplex" steels.

Girod Furnace.—About the same time that Héroult brought out his furnace in France, a man by the name of Girod patented an electric-arc furnace along similar lines in England. This furnace was also circular in form and constructed of steel plates with the usual refractory lining (Fig. 213). It had a shallow hearth and a spout for pouring and was

mounted on rollers. Instead of having all the electrodes on top, however, one set of opposite polarity was installed in the bottom. In a three-phase furnace there were four top electrodes of carbon and sixteen smaller ones of soft iron installed in the bottom around the edge of the hearth. By this arrangement the arc was distributed and passed through the bath vertically, a feature claimed by the inventor to be an advantage. The bottom electrodes were prevented from burning off by a water-cooling system which also protected the hearth lining. The Girod furnace has never been able to compete with the Héroult furnace in the United States.

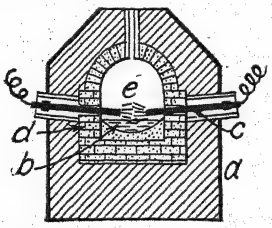

FIG. 214.—Stassano electric-steel furnace. *a.* Outer masonry. *b.* Bath. *c.* Electrodes. *d.* Refractory lining. *e.* Arc. (*After Stoughton.*)

Stassano Furnace.—The Stassano furnace was invented by Stassano, of Italy, and was patented about 1902. Stassano first attempted to produce a furnace that could be used for reducing ores into pig iron and also refining pig iron into steel. But in this he was not successful. He finally gave his attention to the production of a furnace for making steel only, with the result that the Stassano type of electric-steel furnace was developed. In this furnace three equidistant carbon electrodes pierced the side walls on an angle and produced an arc over the center of the bath (Fig. 214). Because of the nearly horizontal position of the electrodes the size of this furnace was limited. Very few of the furnaces

have been built with capacity greater than two tons; consequently they are not extensively used.

The principal advantages of electric furnaces over the crucible type are that there are practically no products of combustion to contaminate the steel, the heat is under perfect control at all times, the operation is much simpler, and the output of steel is larger and less expensive.

CAST STEEL

The term "cast steel" is rather misleading. At first it was applied only to high-grade steel produced in the crucible furnace, but for many years general steel castings were made with a sort of small, modified Bessemer converter (Fig. 215). This furnace differed principally from the regular Bessemer converter in that it was smaller and the charge was largely of molten scrap instead of pig iron. A single tuyere pierced the side and led in a gas flame which impinged upon the surface of the bath instead of an air blast through the bottom. As the demand for steel castings increased, however, this process proved inadequate and too expensive and has been superseded by the open-hearth and electric furnaces. If the castings are large and a fairly steady output is required, the open hearth is used; if they are smaller and of higher grade steel, they are made with the electric furnace.

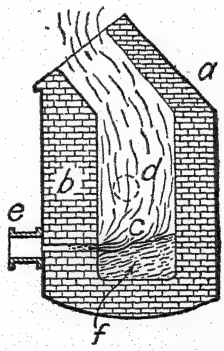

FIG. 215.—Cast-steel furnace. *a*. Steel shell. *b*. Refractory lining. *c*. Gas flame. *d*. Trunnion. *e*. Wind box. *f*. Bath.

Cementation-, Crucible-, Electric-, and Cast-steel Terms

alternating current—An electric current that reverses its direction of flow many times per second, usually twenty-five or sixty.

arc furnace—A metallurgical furnace using the electric arc as its source of heat.

blister steel—Raw-steel bars as they are removed from the cementation furnace, so called because the surface has scales, or blisters, of oxide of iron.

cast steel—A name formerly applied to high-grade steel produced in the crucible furnace.

cementation steel—Steel made in the cementation furnace.

cherry red—Applied to iron heated so that the color is red like a ripe cherry.

crucible—A pot made of fire clay, graphite, Carborundum, or some other highly refractory material used for melting high-fusing metals, as iron, steel, and brass.

crucible steel—Steel made in the crucible furnace, in a crucible.

direct current—An electric current that has a flow in one direction.

double-shear steel—Cementation steel that has gone through the reheating and welding process twice (see shear steel).

electric furnace—A furnace using electricity to supply heat.

electric steel—Steel made in the electric furnace.

electrodes—The poles, or terminals, at a gap in an electric circuit.

Girod—The man who invented an electric furnace with electrodes both above and below the bath, or hearth.

graphite—A metallic, black, flexible, crystalline form of carbon, also called "black lead" and "plumbago."

grog—Old pieces of crucibles sometimes ground up and mixed with fresh materials for new crucibles.

Héroult—A Frenchman who invented the electric-arc furnace with the electrodes suspended from the roof.

induction furnace—An electric furnace using the principle of induction in supplying heat, involving primary and secondary coils.

killing—Allowing the molten steel to remain in the crucible for about forty-five minutes after steeling for the escape of the gases.

lute—To plaster up the cracks in the box holding the charge in the cementation-steel furnace to keep out the air.

melter—The foreman in charge of the melting room.

melting hole—The opening in the floor to the furnace in a melting house.

melting house—The building in which the crucible furnaces for steel making are located.

puller-out—The operator who charges, pulls out, and otherwise manipulates the crucibles.

resistance furnace—An electric furnace in which the heat is generated by the resistance of the medium (generally the charge) through which the current passes.

shear steel—Blister steel that has been cut, piled together, reheated, and welded down into bars.

shingling—Hammering or forging down.

sinter—Partly molten slag, or molten cinder, used to coat over the hearth in a furnace to seal up the crevices and render it tight.

Stassano—An Italian who invented an electric furnace with the electrodes projecting through the sides.

Cementation-, Crucible-, Electric-, and Cast-steel Questions

Group I

1. What kind of iron is used for making cementation steel?

2. How long does it require to make a batch of cementation steel, including the cooling?

3. Name the parts of the furnace.

4. Of what material are the pots for containing the charge?

5. What is meant by "blister" steel, and why is it so called?

6. What steel-making process took the place of the cementation process?

7. Name the materials used for crucibles, and give reasons why these materials are used.

8. What is meant by crucible steel?

9. What object did the inventor of the crucible process have in mind when he developed it?

10. Name the principal materials that can be used for the charge for the crucible furnace.

11. How long does it generally take to make a batch of crucible steel?

12. What is the purpose of killing? How long does it generally take?

13. Mention several articles made from crucible steel.

14. What steel-making process is gradually taking the place of the crucible process?

15. Name the fuels that can be used in the crucible process.

16. Name types of electric-steel furnaces.

17. Give the two principles upon which electric furnaces operate.

18. Of what use is the electric furnace in the production of triplex steel?

19. Explain why the older cast-steel furnace is going out of use.

Group II

20. Why must the bars for cementation steel be thin?

21. Why must the boxes in which cementation steel is made be luted air-tight?

22. What is the main objection to the cementation-steel process?

23. Explain the terms "shear" steel and "double-shear" steel.

24. Why is powdered charcoal instead of larger pieces used in making cementation steel?

25. Why is blister steel harder at the surface than it is in the interior?

26. What determines the size of crucibles?

27. Why are crucibles short-lived? How does this affect the cost of the steel?

28. Why is the charcoal generally put on the top of the steel charge?

29. Explain why crucible steel is more uniform in texture than cementation steel.

30. In general what must be added to wrought iron to make steel?

31. Give reasons why crucible steel is more expensive than Bessemer steel.

32. What is meant by electric steel?

33. Explain why the electric furnace is cleaner than furnaces using coal or other fuels.

34. Explain why it is of an advantage to have an electric furnace installed in the same plant with the Bessemer and open-hearth furnaces.

35. Why is the electric-steel furnace more important than it was a quarter of a century ago?

36. Mention a few articles that would be made of electric steel, and give reason why this steel would be used.

SOME OF THE MORE COMMON ELEMENTS

Name	Symbol
Aluminum	Al
Antimony	Sb
Arsenic	As
Boron	B
Carbon	C
Chromium	Cr
Cobalt	Co
Copper	Cu
Gold	Au
Hydrogen	H
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Molybdenum	Mo
Nickel	Ni
Oxygen	O
Phosphorus	P
Platinum	Pt
Silicon	Si

Name	Symbol
Silver	Ag
Sulphur	S
Tantalum	Ta
Tin	Sn
Titanium	Ti
Tungsten	W
Vanadium	V
Zinc	Zn

ALLOY STEEL

The subject of alloy steels is one of the most important in the whole steel industry, and because of their great number and variety only a few of the more common ones can be discussed in this connection.

Not so many years ago all high-grade steels were known as "carbon" steels because carbon was their main alloying element. If a metal could be obtained that could stand up under ordinary hard usage, it was considered a good steel; but in recent years the enormous demands for high-grade steels with qualities that carbon steel does not possess have made special research work in the subject of paramount importance. To meet these demands, specially equipped laboratories for analyzing and compounding steel materials have become an integral part of nearly every large steel plant.

All steels, strictly speaking, are alloy steels, since they contain at least two elements: iron and carbon. The term "alloy," however, is generally applied only to steels containing at least one other element in addition to these, the number and proportion of elements used being governed by the qualities of steel

desired. The principal alloying elements are manganese, nickel, vanadium, chromium, tungsten, molybdenum, and sometimes copper. It is not to be understood that these elements are always, or even generally, used alone. Often two or more are required to give the steel the desired qualities. Hence, we have so-called "ternary," "quaternary," etc., steels according to the number of major elements that they contain. The name given to an alloy steel is generally taken from its main alloying element, or combination of elements, as manganese steel, chrome-nickel steel, chrome-vanadium-nickel steel, etc.

Carbon Steel.—All steel contains at least a small amount of carbon, but when we speak of "carbon" steel we generally mean a product containing a certain percentage of carbon to give the steel definite degrees of hardness. Up to a few years ago practically all cutting tools were made of carbon steel, but since the development of higher grade steels with other alloying elements the use of carbon steel for that purpose has greatly declined.

Manganese Steel.—High-percentage manganese steel is very tough and hard and difficult to drill or otherwise machine when cold. It is extensively used for jaw crushers, burglar-proof safes, railroad frogs, rails for sharp curves, and in other places where toughness and hardness are the main considerations. Because manganese imparts the quality of toughness it is especially valuable as an alloy for steel wire. Manganese also acts as a deoxidizing agent in a steel bath.

Manganese ores are widely distributed, but only in a few instances are they of sufficient importance to pay for exploiting. The main working deposits are in the Caucasus Mountains in southern Russia, from which more than half of the world's supply is obtained. It is also mined to a limited extent in India, Brazil, Chile, Spain, Austria, Japan, Cuba, France, Great Britain, and the United States. The principal mines in this country are in Montana, Virginia, and California (see Fig. 172).

Nickel Steel.—Aside from carbon, nickel is the element most extensively used for alloying steels. It renders the steel tough, strong, fatigue resisting, and rust resisting. With about 3.5 per cent nickel, the steel can be rolled and forged readily and is extensively used for automobile parts, boiler plate, armor plate, members for long-span bridges, locomotive parts, airplane engine parts, saws, and other tools. With a nickel content of 36 per cent it is known as "invar" and has very little contraction and expansion with ordinary changes of temperature. For this reason it is valuable for clock pendulums, watch and clock parts, and fine measuring instruments. With 45 per cent nickel content it is known as "platinite" and takes the place of platinum wire in electric-light bulbs, where its coefficient of expansion is practically the same as that of glass. A small percentage of nickel added to gray iron renders castings more uniform in hardness and easier to machine.

The principal nickel-bearing ore deposits are in Ontario, Canada, which supplies more than three-

fourths of the world's needs. Ore is also mined in New Caledonia, Norway, and the United States.

Vanadium Steel.—Vanadium is used in steel both as an alloy and as a scavenger. As a scavenger it removes oxygen and other impurities. As an alloy it increases the strength of the steel and promotes grain refinement. Vanadium steel is extensively used for automobile parts, high-speed tools, springs, propeller shafts, tires, and frames and other forgings for locomotives and for castings. Vanadium is also used in dyes, medicines, and other chemical compounds. About half of the world's supply of vanadium ore comes from Peru. The largest percentage of the remainder is mined in Colorado and California (see Fig. 172).

Chromium Steel.—Chromium steel generally contains from 1 to 2 per cent chromium. It is very hard and tough and is used extensively for projectiles, armor plate, files, ball bearings, and cutting tools, and general-purpose automotive alloy steel. Compounds of chromium are used in dyes and in paints, for tanning leather and for bleaching. Chromic ores, or chromite, are widely distributed but are not found to any great extent in one locality. The main producing deposits in the United States are in Oregon and California (see Fig. 172). They are also mined in British South Africa, New Caledonia, Canada, and Brazil.

Silicon Steel.—Steel containing from 1 to 2 per cent of silicon is good for springs. With 3 or 5 per cent it has magnetic qualities and is valuable for

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electromagnets in generating machinery. Added to steel castings, it increases their tensile strength. Silicon is very common. It is the main element in common sand and is found in abundance in all parts of the world.

Tungsten Steel.—Tungsten used as an alloy for steel produces a high-grade metal. It is used extensively for lathe tools, cutters, drills, reamers, finishing tools, cold chisels, and the like. Tungsten steel with about one-half of 1 per cent carbon makes good spring steel. With ¾ per cent carbon and from 5 to 7 per cent tungsten it becomes a permanent magnet. The main producing tungsten-ore deposits are in southeastern Asia and the United States, in which the principal producing states are California, Nevada, Colorado, and South Dakota (see Fig. 172).

Molybdenum Steel.—A small amount of molybdenum added to other alloy steels gives extra tensile strength. Such alloy steels find considerable use in airplane fuselages and automotive parts. They are used to a certain extent as the support for the filament wire for incandescent lights. During the World War a certain amount of molybdenum steel was used for Liberty Motors and armor plate. Ores containing molybdenum are found mostly in the United States and Canada. It is also mined to a limited extent in Norway, Austria, and Australia.

Stainless Steel.—One of the most important developments in recent years has been the production of so-called "stainless steel," or steel that will not corrode (rust) in ordinary atmospheric conditions and that is

not affected by contact with many common acids extensively used in the industries. In general, these steels are known as "18-8" alloys and contain around 18 per cent chromium and 8 per cent nickel together with small percentages of other elements to give them special qualities. They are known by the trade names of "Allegheny metal," USS 18-8, USS 18-12, etc., so designated by the respective producing firms and the amounts of various elements that they contain. They are used extensively for containers for acid materials, for restaurant counters, dairy-plant equipment, bank vaults, automobile construction, high-grade interior trim, etc. (The trim of the Empire State Building in New York is Allegheny metal.)

TYPICAL STAINLESS STEEL (ALLEGHENY METAL)

Element	Per Cent
Carbon	0.08 to 0.12
Manganese	0.50
Phosphorus	0.025
Sulphur	0.025
Silicon	0.50
Chromium	18.00 to 20.00
Nickel	8.00 to 10.00
Iron	Remainder

Other Important Steel and Iron Alloys.—There are many other special alloys on the market with qualities that make them especially valuable for certain kinds of work. Among the more common of these are those known by the trade names of "Durion" and "Enduro."

Durion is a compound of silicon, carbon, manganese, sulphur, phosphorus, and iron. It is practically an

acid-proof metal and is therefore especially valuable for drain pipes, kettles, tanks, etc., where strong acids are used.

Enduro is an alloy of iron, carbon, silicon, chromium, manganese, nickel, and traces of sulphur and phosphorus. It is especially valuable for its non-corroding and stainless qualities. Its uses are practically the same as those for Durion.

As a rule, alloying elements are compounded with iron before being used and are known as ferromanganese, ferrosilicon, ferronickel, etc. The compounds are generally obtained by fusing the respective ores with iron and other elements in the electric furnace.

Photography on Steel.—Recently a process has been developed for photographing on steel. Steel panels can be made to look like marble so closely that only an expert can tell the difference, even to the coloring. Rare woods, in fact almost anything, can be permanently depicted. By the process steel furniture can be made to resemble perfectly curly mahogany, Circassian walnut, and other rare woods.

Alloy-steel Terms

air-hardening steel—Any steel that will harden or retain its temper when being cooled in the air at a normal temperature.

alloy steel—Steel containing at least one other element besides iron and carbon.

chromium steel—An alloy steel having the element chromium as one of its ingredients. A special tool steel.

copraloy—A special alloy steel containing copper as one of its elements.

high-speed steel—Any alloy steel that will retain its temper when heated by friction, as with tools, when cutting.

invar—Special nickel steel containing 36 per cent nickel; very low coefficient of expansion.

manganese steel—An alloy steel having the element manganese as one of its main ingredients. Very hard, tough steel.

Mushet steel—An alloy steel having definite proportions of tungsten, carbon, and manganese in its composition.

nickel steel—An alloy steel having the element nickel as one of its main ingredients.

platinite—A nickel-alloy steel containing 46 per cent nickel; coefficient of expansion similar to that of platinum.

quaternary steel—Steel containing four major elements.

self-hardening steel—Same as air-hardening steel.

silicon steel—An alloy steel having the element silicon as one of its principal ingredients.

ternary steel—Steel containing three major elements.

tungsten steel—An alloy steel having the element tungsten as one of its principal elements.

vanadium steel—An alloy steel having vanadium as one of its principal ingredients.

Common Tests for Steel for Automobile Construction

Yield point	Torsional strains and stresses
Elastic limits	Deflection, inches per pound
Tensile strength	Impact
Elongation, per cent	Wear
Reduction of area, per cent	Many fatigue tests
Hardness	Weather or accelerated weather

Typical Automobile Alloy Steels[1]

Note.—It will be observed that practically all of these steels have a silicon base. The missing percentage is iron with slight traces of other elements which do not impair the quality of the steel.

[1] Courtesy of Society of Automotive Engineers.

Carbon Steel

	Per Cent
Carbon	0.40 to 0.50
Manganese	0.60 to 0.90
Phosphorus	0.045
Sulphur	0.055

Nickel-chromium Steel

	Per Cent
Carbon	0.10 to 0.20
Manganese	0.30 to 0.60
Phosphorus	0.040
Sulphur	0.050
Nickel	1.00 to 1.50
Chromium	0.45 to 0.75
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Molybdenum Steel

	Per Cent
Carbon	0.25 to 0.35
Manganese	0.50 to 0.80
Phosphorus	0.040
Sulphur	0.050
Chromium	0.50 to 0.80
Molybdenum	0.15 to 0.25
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Silico-manganese Steel

	Per Cent
Carbon	0.50 to 0.60
Manganese	0.60 to 0.90
Phosphorus	0.040
Sulphur	0.050

Silicon	1.80 to 2.20
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Nickel Steel

	Per Cent
Carbon	0.10 to 0.20
Manganese	0.30 to 0.60
Phosphorus	0.040
Sulphur	0.050
Nickel	3.25 to 3.75
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Chromium Steel

	Per Cent
Carbon	0.15 to 0.25
Manganese	0.30 to 0.60
Phosphorus	0.040
Sulphur	0.050
Chromium	0.60 to 0.90
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Chromium-vanadium Steel

	Per Cent
Carbon	0.15 to 0.25
Manganese	0.30 to 0.60
Phosphorus	0.040
Sulphur	0.050
Chromium	0.80 to 1.10
Vanadium	0.15 to 0.18
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

TUNGSTEN STEEL

	Per Cent
Carbon	0.50 to 0.70
Manganese	0.30
Phosphorus	0.035
Sulphur	0.040
Chromium	3.00 to 4.00
Tungsten	12.00 to 15.00
Silicon:	
Basic open hearth	0.15 to 0.30
Electric and acid, open hearth	0.15

Alloy-steel Questions

GROUP I

1. What is meant by an alloy?

2. What is an alloy steel?

3. In what sense can all steels be considered alloy steels?

4. In general, to what kind of steel is the term "alloy" applied?

5. What general quality does each of the following elements give to steel: carbon, manganese, nickel, silicon, chromium, tungsten, vanadium?

6. Explain the following terms: "ternary steel," "quaternary steel."

7. What is self-hardening steel?

8. How are ferromanganese, ferronickel, ferrochromium, etc., produced?

9. In what general types of furnace are high-grade alloy steels produced?

10. Name some of the more common alloy steels.

GROUP II

11. What is the general purpose of alloying steel?

12. Explain why there are so many varieties of alloy steels in use.

13. Why is self-hardening steel more economical for cutting tools than plain carbon steel?

14. How does the automobile industry affect the alloy-steel industry?

15. What general quality must steel for rock-jaw crushers possess?

16. What general quality should steel for fine measuring instruments possess?

17. In what way does chemistry aid in steel making?

18. What two special qualities must steel for high-grade cutting tools possess?

19. Why is a series of tests necessary in producing alloy steel?

20. In what important respect must the quality of steel for files differ from structural steel?

CAST IRON AND MALLEABLE CAST IRON

The simplest form of iron as well as the cheapest to produce is "cast" iron, so called because its raw materials are melted and cast into moulds to secure desired forms. Many castings are practically ready for use as soon as they come from the moulds and are cleaned, but for the most part they must be turned, drilled, planed, or otherwise machined before they are finished.

Cupola Furnace.—Cast iron is produced in what is known as the "cupola furnace," which consists of a straight steel shell or shaft lined with refractory materials (Fig. 216). Unlike the blast furnace, the top is open for the escape of the waste gases, and a door is constructed in the side for charging instead of the bell-and-hopper device at the top. A wind box encircles the base, from which tuyeres lead the blast to the melting zone. Just below the wind box

at the bottom of the melting zone is a tap hole, and a little higher up is a slag hole. The entire bottom is closed by a pair of drop doors which can be opened at the end of each heat to allow for cleaning and making repairs.

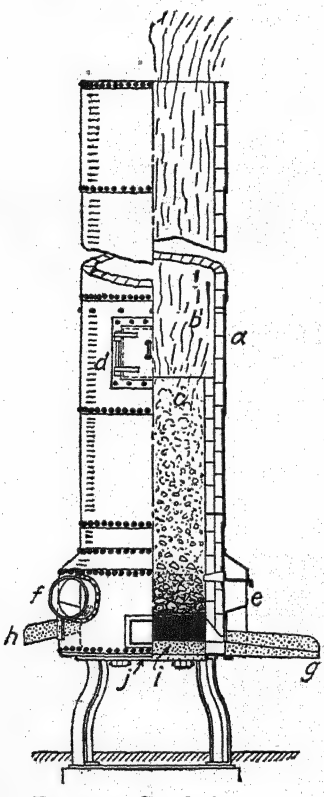

FIG. 216.—Cupola furnace. *a.* Steel shell. *b.* Refractory lining. *c.* Charge. *d.* Charging door. *e.* Wind box. *f.* Wind pipe. *g.* Iron spout. *h.* Slag spout. *i.* Sand bottom. *j.* Drop doors. (*Courtesy of Quigley Company, Inc.*)

The charge of a cupola generally consists of pig iron and scrap iron in different proportions to meet different requirements, and the fuel is generally coke. Flux in the form of oyster shells, marble chippings, fluorspar, etc., is used when required for special grades of iron. The operation of the furnace requires special training and skill. In making soft gray castings for machining, the charge mixture must be considerably different from that used for hard white iron. The fusing points of the pig iron and scrap must be taken into account, and the fluxing materials must be carefully selected and proportioned if the best results are to be obtained.

Electric-furnace Cast Iron.—In recent years the practice of melting cast iron for gray iron castings in an arc-type furnace has come extensively into use. This has the advantage of utilizing borings and other poorer grades of scrap for the charge that could not be

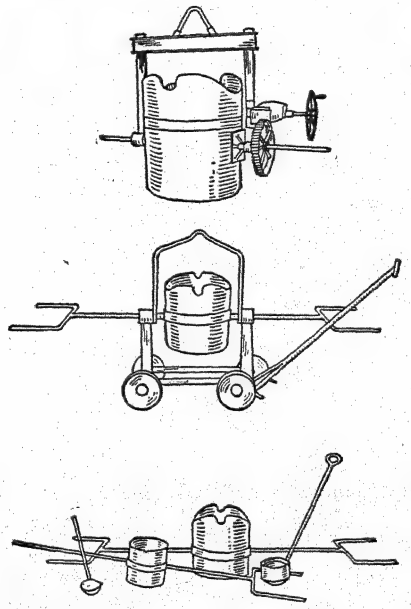

FIG. 217.—Typical ladles used in foundry practice. (*After Stoughton.*)

used for a good grade of iron with the cupola furnace. During the process a certain amount of refining is possible that results in a high grade of metal. It is also possible to produce a "synthetic" cast iron from steel scrap in the electric furnace by adding a proper amount of carbon to the melt.

Common Foundry Practice.—It is a common practice in most foundries to use the earlier part of the day in making moulds and to start the furnace just

in time to have the metal ready for pouring when the mould-making process is finished. When the furnace is started, wood is placed in the bottom and covered with coke. Alternate layers of iron and coke are then introduced until the charge reaches the charging door. The fire is now lighted and the blast is turned on, and in about thirty minutes iron will begin to flow. As soon as enough is accumulated in the bottom of the hearth, the operator, or cupola man, opens the tap hole with a tapping bar and the fiery metal begins to flow down the spout. It is generally caught in a bull ladle from which it is poured into smaller ladles as needed for casting. The tap hole is stopped by the operator with a clay bott plug on the end of a bott stick. As the charge settles, new materials are added until enough metal is melted for the day's casting.

It is a very busy time in the foundry when the moulds are being poured. Men are carrying small ladles here and there, filling small moulds; and large ladles handled by powerful cranes are delivering metal to the larger ones (Fig. 217). Now and then loud reports are heard as moulds explode from burning gases. Everywhere thin sheets of blue and other colored flames are seen issuing from the crevices in the flasks, and clouds of steam rise as the hot metal comes into contact with the damp sand.

After the iron is all drawn off, the bottom doors of the furnace are dropped, and the interior allowed to cool so that it can be cleaned and repaired ready for the next day's operation.

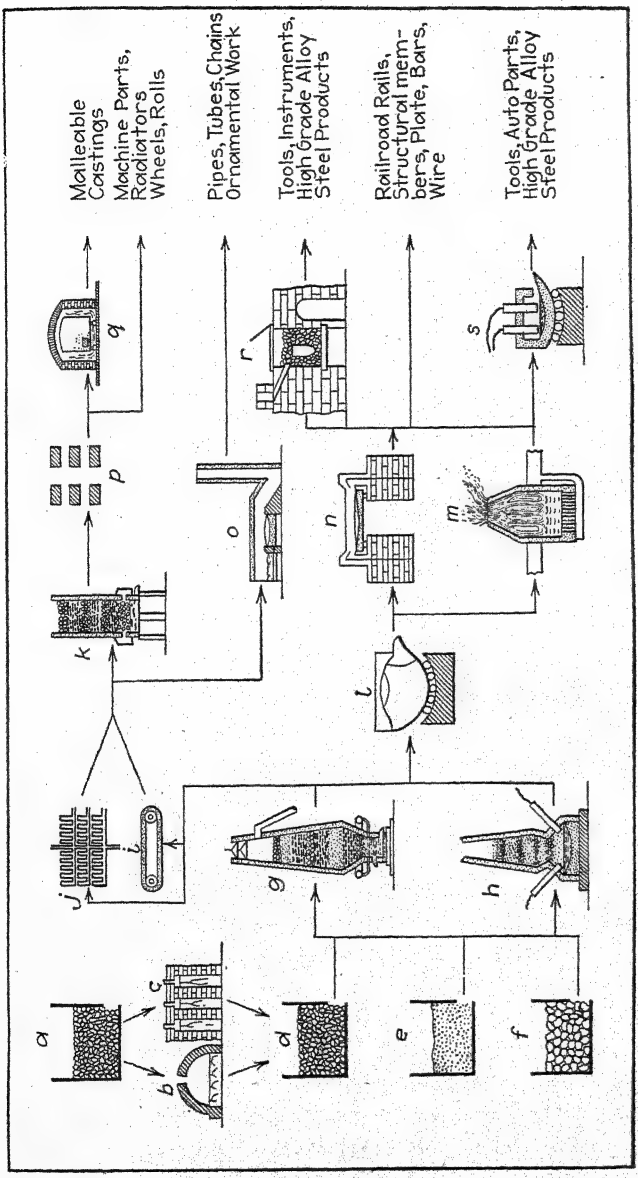

FIG. 218.—Iron and steel production. *a.* Bituminous coal. *b.* Beehive coke oven. *c.* By-products coke oven. *d.* Coke. *e.* Iron ore. *f.* Limestone. *g.* Blast furnace. *h.* Electric smelting furnace. *i.* Pig casting machine. *j.* Sand or casting floor. *k.* Cupola furnace. *l.* Mixer. *m.* Bessemer converter. *n.* Open-hearth furnace. *o.* Hand-puddling furnace. *p.* Cast-iron castings. *q.* Annealing furnace. *r.* Crucible furnace. *s.* Electric-steel furnace.

Malleable Cast Iron.—Malleable cast iron, or iron that can be worked cold and that will withstand sudden shock, is a crude form of wrought iron. It is produced by first casting a good grade of cast iron into the desired form and, after thoroughly cleaning the castings, annealing them in a special annealing furnace. A common type of annealing furnace consists of an air-tight iron or stone box into which the castings are packed with some form of iron oxide. The boxes and their contents are placed in a chamber and heated to a temperature from 600 to 1600°F. for about three days and then allowed to cool gradually. By this treatment a portion of the carbon is oxidized, and the remainder is converted into graphite and no longer renders the iron brittle.

Malleable castings have a wide variety of uses where a medium grade of malleable iron is required. Among the more common are railroad-car journal boxes, bumpers and other car fittings, parts of agricultural implements, pipe fittings, household and harness hardware, hammers, and other tools.

Cast-iron and Malleable Cast-iron Terms

anneal—To reduce the brittleness and increase the softness and toughness in a material, as glass and the metals.

annealing box—A stone or metal container for holding articles that are being annealed.

annealing furnace—A furnace especially designed for annealing.

bott plug—A clay ball used for stopping the tap hole in a cupola furnace.

bott stick—A long stick used for inserting the bott plug into the tap hole to stop the flow of metal.

cast iron—Iron generally melted in the cupola furnace and sometimes in the electric furnace and used for castings in the foundry.

cupola furnace—A furnace generally used for melting cast iron in the foundry and consisting of an upright metal shell lined with fire brick.

drop doors—Hinged doors closing the bottom of the cupola furnace which drop down to allow the furnace to be cleaned.

gray cast iron—Soft cast iron in which the carbon is largely in the form of graphite (easily machined).

ladle—A refractory-lined container into which the molten iron is drawn and from which it is poured into the moulds.

malleable iron—Cast iron that has been made malleable by the annealing process.

white cast iron—A very hard and brittle iron containing a high percentage of carbon in the form of cementite, a compound of iron and carbon very hard to machine.

Cast-iron and Malleable Cast-iron Questions

Group I

1. Describe a cupola furnace.

2. Name the materials of charge of a cupola furnace.

3. When should flux be used in a cupola furnace?

4. Why are cupola furnaces generally run in the latter part of the day?

5. Of what advantage are the drop doors at the bottom of the furnace?

6. Name several articles made of common cast iron.

7. Of what material is malleable cast iron made?

8. What element in cast iron must be changed to make malleable cast iron?

9. What change does annealing bring about in cast iron?

10. State briefly the process of producing malleable cast iron.

11. How much time is generally required to anneal malleable cast iron?

12. At what temperature is annealing generally done?

13. Mention several uses for malleable castings.

14. What kind of cast iron is generally made in the electric furnace?

15. What takes place in the electric furnace that makes it possible to use poorer materials for the charge?

16. Explain what is meant by "synthetic" cast iron.

Group II

17. What should govern the size of a cupola furnace?

18. Why are cupola furnaces not run continuously?

19. Explain the use and advantage of the bull ladle.

20. Why are malleable castings better for certain purposes than common cast-iron castings?

21. Why must the box in which malleable castings are annealed be air-tight?

22. Why is the malleable cast-iron furnace also called an annealing furnace?

23. When should small and when should large ladles be used in a foundry?

24. Name the general materials used in the construction of a ladle.

Iron and Steel Metallurgy

Definitions of Terms and Processes Common to the Industry[1]

Iron ore—Contains iron and oxygen and impurities. Smelted in blast furnace, removing oxygen and part of impurities and adding carbon, makes..... **Pig iron**

Foundry pig iron—Melted in cupola and cast makes.. **Iron castings**

Iron castings—Made from malleable pig iron and heated in scale make..... **Malleable castings**

Gray forge pig iron—Melted in a puddling furnace, then balled, squeezed, and rolled, makes..... **Muck bar**

Muck bar—Or wrought scrap cut into short lengths, piled, heated, and rolled, makes..... **Wrought iron**

[1] Courtesy of Metals Market.

Muck bar—Treated as above and rolled into strips makes **Skelp iron**

Skelp iron—Bent into the shape of tubes and welded makes **Iron pipe**

Muck bar—Or steel melted in a crucible with charcoal, makes carbon steel, tool steel, or..... **Crucible steel**

Bessemer pig iron—Direct from blast furnace or melted in cupola, poured into converter, with air blown through it to burn out the impurities, makes..... **Bessemer steel**

Pig iron—Molten, or in pig, with or without scrap, when purified in open-hearth furnace makes.... **Open-hearth steel**

Low-phosphorus pig iron—Treated as above in an acid (silica or sand)-lined furnace makes..... **Acid open-hearth steel**

Basic pig iron—Treated as above in a basic (dolomite)-lined furnace to remove phosphorus makes **Basic open-hearth steel**

Pure iron—The product of a basic open-hearth furnace refined to a point where the impurities are reduced to the lowest practicable minimum, after which copper and molybdenum are added in correct proportions, is..... **Toncan copper-molybdenum iron**

Pig iron—Is poured into moulds making..... **Pigs**

Ingots—Are rolled into..... **Blooms or billets**

Ingots—Are rolled into..... **Slabs**

Blooms—Are rolled into..... **Rails**

Blooms—Are rolled into..... **Structural shapes**

Slabs—Are rolled into..... **Plates**

Billets—Are rolled into..... **Bars and small shapes**

Billets—Are rolled into..... **Steel skelp**

Billets—Are pierced, rolled, and drawn through dies, making **Seamless tubes**

Billets—Are rolled into..... **Rods**

Steel skelp—Bent into the shape of tubes and welded makes **Steel pipe**

Rods—Are drawn through dies into..... **Wire**

Rods—Are headed into..... **Rivets and bolts**

Rods—Are welded into..... **Chain**

Wire—Is made into.....**Nails and fencing**
Ingots—Are rolled into.....**Sheet bars**
Sheet bars—Are rolled into.....**Black sheets**
Black sheets—Cleaned, cold rolled, coated with tin make .**Tin plate**
Black sheets—Cleaned, cold rolled, coated with lead and tin make.....**Terne plate**
Black sheets—Cleaned, cold rolled, and coated with spelter (zinc) make.....**Galvanized sheets**
All sheets—Can be stamped into.....**Various forms**

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CHAPTER IV

NON-FERROUS METALS

COPPER

Historical Sketch.—Copper gets its name from the word *cuprum,* the old Latin word for the island of Cyprus. It is known that in very early times practi-

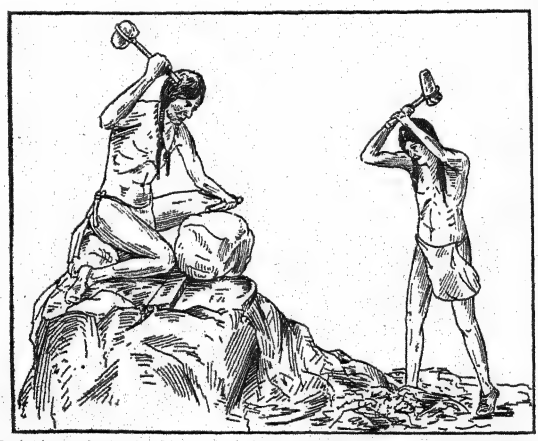

FIG. 219.—American Indians mining native copper and making implements. (*Courtesy of American Museum of Natural History.*)

cally the world's supply came from that country. Probably it was the first metal used by man. It is not difficult to imagine that some lumps of native copper had melted in a camp fire and taken the form of the hollow in the ground into which it had run. The early savages must have soon discovered that the

strange new material could be worked into forms and sharpened to an edge much better than the stones which up to this time they had used. At any rate, we have abundant evidence that the metal was smelted and used long before the dawn of recorded history.

In Egypt, graves containing weapons and other utensils are found dating back as early as 5000 B. C. A bronze rod taken from one of the pyramids is believed to be over six thousand years old. Copper was also early mined and smelted in Spain, Great Britain, and other European countries; and relics found in North and South America prove that it was used by our own aborigines long before the time of Columbus. Remains of prehistoric copper industries still exist around the Lake Superior region, where nature scattered large nuggets of native copper pure enough for use without any special refining. In some instances masses of copper in this section were so large that efforts to remove them after they had been loosened from their beds were abandoned. Crude mining tools are often found around these early workings.

Aside from the great numbers of prehistoric weapons and utensils found in graves and ruins, we have many evidences of the use of copper in old monuments still in existence—for instance, the bronze snake in Constantinople cast in 479 B. C. and the four famous bronze horses early brought to Venice from Rome.

Source of Copper.—As is well known, copper is obtained from ores of which there is a large variety.

Among the most common are chalcocite, a copper sulphide, enargite, a copper arsenic sulphide, bornite, a copper iron sulphide, chalcopyrite, azurite, and malachite. They often contain gold, silver, platinum, arsenic, lead, zinc, iron, and other elements. In fact, they are sometimes worked with copper as a by-product but in such cases are not apt to be called "copper" ores. They range in color from light gray to black through beautiful hues of green, blue, and violet. In certain localities the colors are so beautiful that the ores are made into vases and other works of art. Often the banded stones set in rings and other jewelry are malachite; jewelers, however, are not apt to advertise their wares as being set with copper ore. Chalcocite is the ore most extensively used for the production of copper. It is a copper sulphide with the formula Cu_2S and sometimes contains as much as 79 per cent copper. It is of a grayish lead color, generally with a green tarnish. Another important ore is enargite, a copper-arsenic sulphide with the formula Cu_3AsS_4. Because of its large percentage of arsenic, enargite was formerly considered of little value as a copper producer; but improved methods of treating and refining have made it valuable as a source not only of copper but also of arsenic as a by-product. Bornite, a copper iron sulphide, is also extensively smelted for copper. Its formula is Cu_5FeS_4.

Deposits.—Copper ores, like iron and coal, are distributed widely over the face of the earth. At the present time the United States leads all other countries in development of her deposits, furnishing the

largest percentage of the world's supply. Chile ranks second, and Africa third, followed by Canada, Spain

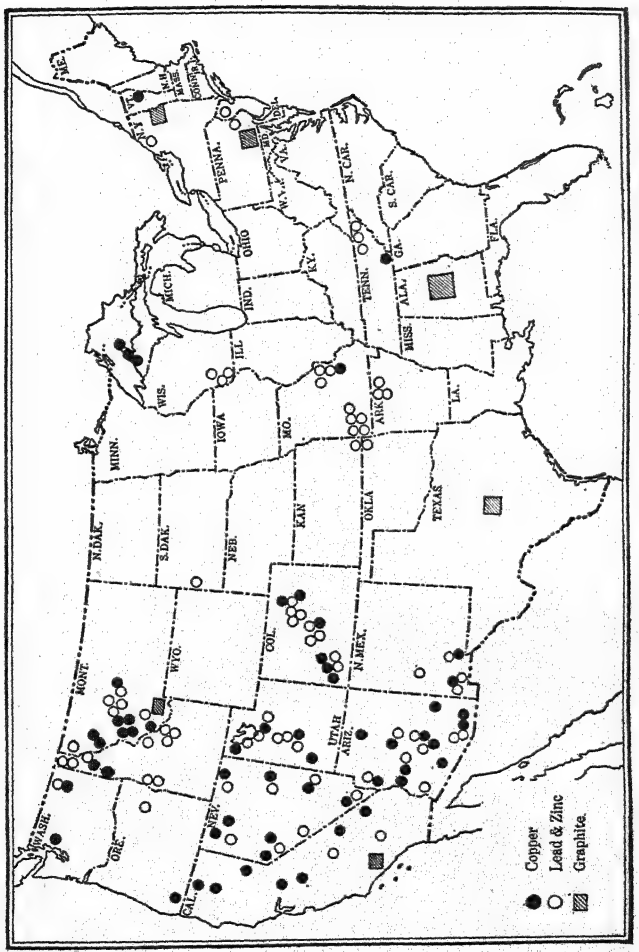

FIG. 220.—Copper, lead, zinc, and graphite deposits in the United States.

and Russia, although the order is likely to change from time to time. Our leading producing states rank as follows: Arizona, Montana, Utah, and Michigan.

Among other states that produce considerable quantities are California, New Mexico, Colorado, Tennessee, and Nevada (Fig. 220).

In the early history of the copper industry in this country several deposits were worked in the Eastern states. One of these was at Arlington, N. J., where the remains of an old mine can still be seen. In time, however, the richer mines of the Lake Superior district and the Rocky Mountains began to be opened up, and many of the Eastern workings were abandoned. About 1875 the copper beds of Montana were opened up and began to be worked systematically. As the mining progressed, the deposits proved to be of far greater extent and richer than anyone had anticipated.

For many years the mines around Butte have been famous the world over. One large company owns and operates mines in this section involving underground passageways totaling over 1,000 miles in length; and several miles are being added each year. Twenty-nine air shafts handling more than 2,000,000 feet of air per minute are required to keep these mines ventilated so that the miners can work. More than 120,000,000 tons of copper ore have been mined in this section in the past fifty years—enough to fill a train that would reach halfway round the world. From this ore over 1,000,000,000 pounds of copper have been smelted—enough to make a telephone wire that would reach halfway to the sun. For the most part, these mines are deep, some of them running down to 4,100 feet. The single mine producing the

largest tonnage of ore in this country at the present time is at Bingham, Utah. Here is a great mountain of ore that can be worked by open-pit methods, a decided advantage. Other famous open-pit copper mines are at Chuquicamata, Chile; and Rio Tinto, Spain. (The Rio Tinto mine is famous not only at the present time as a copper producer but also historically as well. It is known that it was worked by the Phoenicians as early as 1240 B. C.) The deepest copper mine in the world at the present time is in northern Michigan, where a vertical depth is reached of over two miles. Here also are some of the richest mines. In some instances the ore is so rich that smelting is all that is necessary in the process of refining to produce copper of sufficient purity for certain purposes. It is known that the Indians mined and used this copper before the white men came.

The processes of mining copper ores do not differ essentially from those used for coal and iron ore. The ore is blasted loose, broken up, loaded into cars, and brought to the surface. Formerly only the richer deposits were used (sometimes these contained as much as 50 per cent copper), but as these became scarcer and better methods of extracting developed, the poorer deposits were worked until at the present time those containing even less than 1 per cent copper can be utilized with profit, as at Miami, Ariz.

Concentrating.—As a rule, before copper ore can be smelted with profit, it is necessary to separate it, in part at least, from the gangue, or worthless rock, with which it is always associated. This is accomplished by

processes known as "concentrating." One of the largest concentrating plants is at Anaconda, Mont., about 25 miles from the great mines of Butte, located there because of an adequate water supply, of which large quantities are required. The ore is first crushed fine, an operation that is accomplished in stages by various types of crushers. All along the line it is

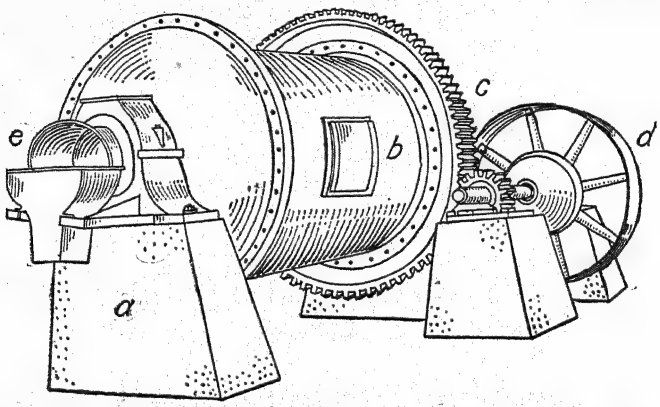

FIG. 221.—Ball mill. *a.* Foundation. *b.* Shell. *c.* Gear. *d.* Pulley. *e.* Discharge hopper. (*Courtesy of Allis-Chalmers Manufacturing Company.*)

washed and screened to remove as much worthless material as possible. If it contains iron, this can be eliminated by passing the crushed ore under electromagnets. Other impurities are removed by taking advantage either of the difference in specific gravity between the richer and poorer particles of ore or of the greater tendency of an oil film to cling to particles of ore containing a higher sulphide percentage of copper mineral.

When the former principle is used, the ore is crushed into pieces no larger than fine sand and introduced

into special jigs, classifiers, or other apparatus in which it is shaken in the presence of water in the same way that jigs are used for picking slate from coal. The current of water carries the finer and lighter particles away, leaving the heavier and richer ore behind. The same principle is employed in concentrating ore on

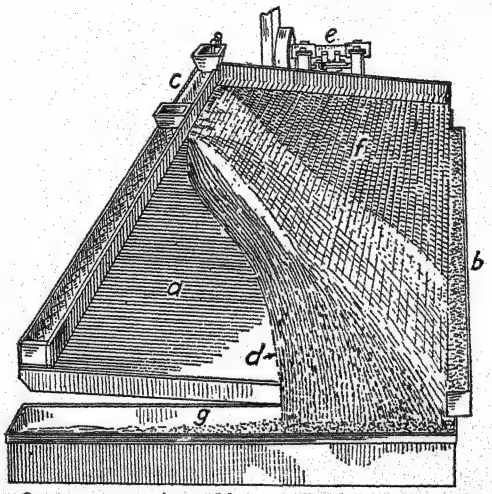

FIG. 222.—Ore-concentrating table. *a*. Table. *b*. Launder. *c*. Feed. *d*. Concentrates. *e*. Shaking mechanism. *f*. Slime. *g*. Concentrate box. (*Courtesy of International Correspondence Schools.*)

horizontal tables or decks. The tables used have rounded grooves and ridges in their surfaces similar to the ripples in fine sand on a beach (Fig. 222). The fine ore is run on to these tables in water, and a jerking motion causes the heavier materials to collect in the grooves and pass out at their ends, while the lighter materials are forced over the ridges and pass off at one side. Somewhat similar phenomena can be

seen in the formation of a small sand bar in a stream of water.

The other principle in much more general use is known as "flotation," because the richer pieces of ore are caused to float. The ore is crushed into very fine powder and introduced into special flotation machines which are specially constructed tanks supplied with a solution of water, oil—generally pine oil—and some chemicals and a mechanism for agitating. As the solution is agitated into an emulsion, it fills with minute air bubbles which are surrounded by an oil film. The oil films and air bubbles adhere to the richer particles of ore, causing them to rise to the surface leaving the gangue behind (Fig. 223). A similar phenomenon can be seen when dirt collects in the foam on soap suds. As a further development of the flotation principle, it is now possible to separate other mineral-bearing ores from the copper ore by using certain chemicals in the solution. Such concentrating is known as "selective flotation." The selective flotation process rejects about 70 per cent of the iron, more than 95 per cent of the siliceous material, and recovers more than 95 per cent of the copper. The rejects are leached to obtain most of the remaining copper. By the flotation process ores containing as little as 1 per cent copper can be concentrated into a

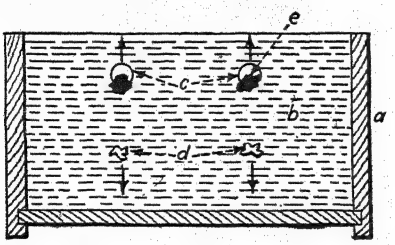

FIG. 223.—Principle of flotation. *a.* Tank. *b.* Solution. *c.* Air bubble. *d.* Worthless rock, *e.* Richer ore.

product containing as much as 30 per cent or more of copper.

After the concentrating processes, the water is removed from the ore by filtering or otherwise. It is now roasted in special furnaces to remove sulphur and as many other volatile impurities as possible and is ready for smelting (Fig. 224) and is known as "calcine." It is interesting to note that, once the roasting furnace is started, no extra fuel is needed, the heat being kept up by the burning of the sulphur in the concentrates.

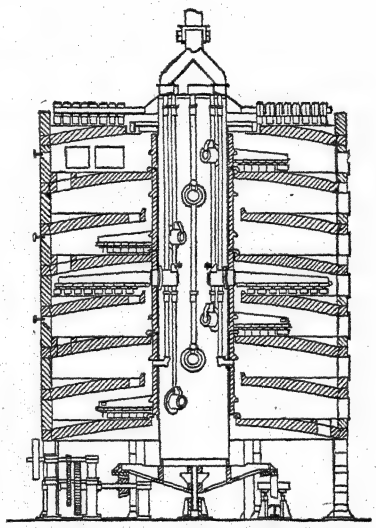

FIG. 224.—Ore-roasting furnace. (*Courtesy of Bureau of Mines.*)

Leaching.—In recent years the recovery of copper from very lean oxidized ore by leaching has received considerable attention, and tailings containing only a few pounds of copper per ton can be leached with profit. In this process the pulverized tailing ore is immersed in a bath of dilute sulphuric acid which dissolves the metallic copper from the worthless rock just as salt or sugar would be dissolved from a mixture of sand in a glass of water. The copper is afterward precipitated from the solution by electrolytic action and by passing it through scrap iron.

Smelting and Oxidizing.—Formerly a part of the smelting was done in blast furnaces, using only the coarser and richer ores, but in recent years the tendency is to use only the reverberatory furnace for the purpose because of its greater economy in the treatment of fine ores and concentrates. Reverberatory furnaces for copper do not differ materially from open-hearth furnaces for steel. The larger type is about 24 feet wide by 140 feet long. The fuel used is generally pulverized coal or fuel oil, and the product is crude copper matte containing from 38 to 42 per cent copper. The molten matte goes directly from the smelting furnaces to the converters or oxidizing furnaces for further refining.

Oxidizing Copper Matte.—A typical converter consists of a steel shell lined with refractory brick weighing, with its charge, about 300 tons, the charge itself weighing about 65 tons. It is mounted on trunnions so that it can be tilted to receive the charge and pour out the metal in a manner similar to the action of the Bessemer converter for steel (Fig. 225). An air blast is sent through the bath for five or six hours, burning out most of the sulphur and oxidizing the iron. The burning gases at the nose of these converters are as spectacular as those of the Bessemer converter.

They often contain considerable copper dust, which is collected in brick chambers and sent back to the furnace for resmelting. The product of the converters is about 99 per cent pure copper and is known as "blister copper" because of the blister-like appearance of the surface when cast into cakes. The principal

foreign elements in the copper now are gold, silver, arsenic, antimony, lead, zinc, and oxygen.

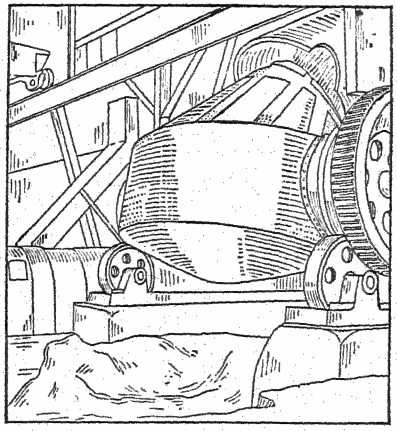

FIG. 225.—Copper-refining converter.

The blister copper comes to the refinery in the form of slabs weighing about 350 pounds each. These are melted in reverberatory furnaces known as

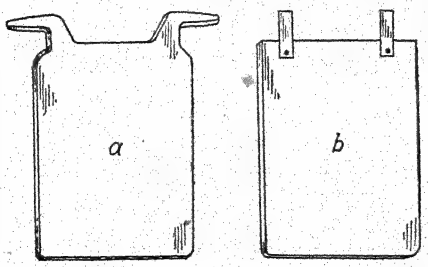

FIG. 226.—Copper refining. *a*. Anode. *b*. Cathode.

"blister furnaces," the details of their operation including oxidizing and poling being practically the same as in the final refining furnaces described later on. In this melting process some of the impurities are

removed with the slag, and the remaining sulphur is practically eliminated. The copper is next cast into anodes (slabs) about 37 inches long by 28 inches wide by 2 inches thick weighing about 750 pounds each and with lugs at two opposite corners for supporting them in the tanks (Fig. 226*a*). A typical assay of the anodes of Anaconda copper is as follows:

Copper	99.25 per cent
Silver	30.0 oz. to the ton
Gold	0.40 oz. to the ton
Arsenic	0.060 per cent
Antimony	0.022 per cent
Nickel	0.050 per cent
Lead	0.053 per cent
Iron	0.058 per cent
Bismuth	0.003 per cent
Sulphur	0.004 per cent
Selenium	0.048 per cent
Tellurium	0.038 per cent
Oxygen	0.100 per cent

Thin starting sheets of practically pure copper are provided for the cathodes (Fig. 226*b*).

Electrolytic Copper Refining.—The next step in the refining process is to remove the foreign metals, not only in order to render the copper pure enough for special kinds of work but also for the profits derived from the metals themselves. This is accomplished by what is known as the "electrolytic process," or "electrolysis." A typical plant for electrolytic copper refining is equipped with a series of lead-lined wooden or cement tanks about 118 inches long by 34 inches wide and 44 inches deep (Fig. 227*A*, *B*).

They are fitted on the top edges with proper connections for supplying electric current. A solution of copper sulphate and sulphuric acid (the electrolyte) is introduced, partly filling the tanks. Into these tanks the anodes and cathodes are hung in such a manner as to form the two poles of an electric circuit.

There are two methods of arranging the tanks for this purpose: the multiple method and the series

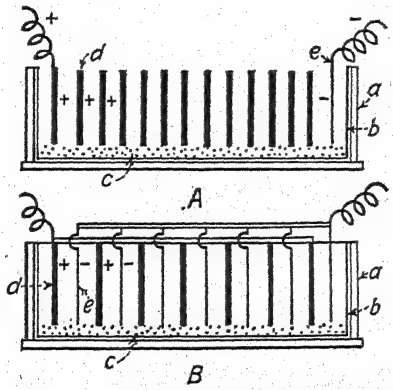

FIG. 227.—Electrolytic copper-refining tanks or cells. *A*. Series process. *B*. Multiple process. *a*. Wooden or cement tank. *b*. Lead lining. *c*. Slime. *d*. Anodes. *e*. Cathodes.

method. In the multiple method the anodes and cathodes are alternated (Fig. 227*B*), and in the series method several anodes are used with only one cathode placed at the end of the tank (Fig. 227*A*). Of course the anodes connect with the positive end of the circuit, and the cathodes with the negative end. A current of about 7,000 amperes is sent through the solution which dissolves the copper from the anode and deposits, or plates, it on the cathodes. The gold, silver, arsenic, and other foreign metals are released

and settle to the bottom of the tank in the form of slime. The precious metals are recovered by casting the slime into anodes and using electrolytic refining. Silver nitrate is used for the electrolyte for silver, and hydrochloric acid and gold chloride for gold. When the cathodes have increased to about 170 pounds they are replaced by new thin starting sheets. As a rule three cathodes are required for one anode.

The product is now about 99.98 per cent pure and is ready for the final melting and refining process before being cast into commercial forms. The following is a description of the final refining process:

The cathode copper, containing as it does 99.98 per cent copper, should be an easy melting proposition, but copper when molten absorbs reducible gases, more particularly sulphur, to such an extent that the melting process becomes a refining process, refining from the gases absorbed during the period of melting. The presence of oxygen, or rather copper suboxide, greatly increases the solubility of these gases in cast copper, and it is for this reason that from 0.03 to 0.08 per cent oxygen will always be found in commercial copper.

The copper is melted in large reverberatory furnaces of 250 to 350 tons capacity. The furnaces are lined with magnesite bricks up to above the metal line and with silica brick roof and sides above that. The fuel is pulverized coal, and the gases on leaving the furnace are conducted through waste-heat boilers. The melting or refining operation may be divided as follows:

1. Charging.
2. Melting.
3. Oxidizing.

4. Poling.
5. Casting.

All operations are so conducted that it takes about twenty-four hours to work the complete cycle of a charge.

1. *Charging.*—Charging was formerly done by hand, a laborious operation, but now all furnaces are charged with a charging machine. The machine picks up 29 cathode sheets weighing about 4,500 pounds at a time and puts them in the furnace much more completely than could be done by hand, thus materially increasing the capacity of the furnace. The time of charging a furnace is usually two hours.

2. *Melting.*—After the furnace is charged, the side doors are closed and luted, and the fire increased to hasten the fusion of the copper. In about ten to twelve hours enough copper has melted so that the oxidation period can begin.

3. *Oxidizing.*—In this period the molten copper is nearly saturated with cuprous oxide and brought to what is known as "set copper" containing from 7 to 9 per cent of suboxide of copper. In this process all impurities are oxidized, and all hydrogen, carbon monoxide, and sulphur compounds are removed.

This is accomplished by blowing compressed air through iron pipes inserted into the molten bath, also by "flapping" the charge. Flapping consists in striking the surface of the metal with the edge of the head of a rabble, in order to uncover the surface of the copper.

The furnace man watches the operation by taking button samples and observing the fracture, which is characteristic and well defined at all stages.

4. *Poling.*—During the oxidizing period successive formations of slag are skimmed off. The bath is then covered with coke or charcoal, and the "poling" process begins.

This consists of forcing the butt ends of green poles underneath the surface of the metal. This causes a violent action in the metal bath, and the carbon from the wood and coke quickly reduces the dissolved cuprous oxide. This operation takes two or three hours. When the suboxide of copper has been reduced to from 0.3 to 0.6 per cent, which can be readily told by the fracture of the button sample, the copper has reached the "tough-pitch" stage and is ready for casting.

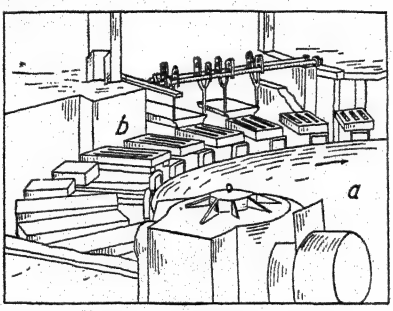

FIG. 228.—Commercial copper form-casting machine. *a*. Casting wheel, or table. *b*. Moulds. (*Courtesy of Anaconda Copper Mining Company.*)

5. *Casting.*—This operation consists of casting the molten copper into commercial shapes, wire bars, slabs, wedge bars, cakes, ingots, ingot bars and billets (Fig. 228). The moulds are made of copper and sprayed with a bone-ash emulsion. The moulds are placed radially in a circular casting machine known as the "Clark casting machine." As the wheel turns around, the moulds are filled with copper from the furnace. After the copper has set, the moulds automatically tip, dropping the copper bars into a water bosh, which cools the copper and gives it the characteristic red color. The bars come up from the bosh on an endless belt and after weighing are ready for shipment.[1]

Commercial forms of copper are regulated by the use for which they are intended (Fig. 230). Wire bars, for

[1] Courtesy of Anaconda Copper Mining Company.

drawing wire, are cast with roughly pointed ends in order that they may be easily gripped by the rollers in the early stages of rolling. They vary in length from 39 to 100 inches and in weight from 35 to 700 pounds.

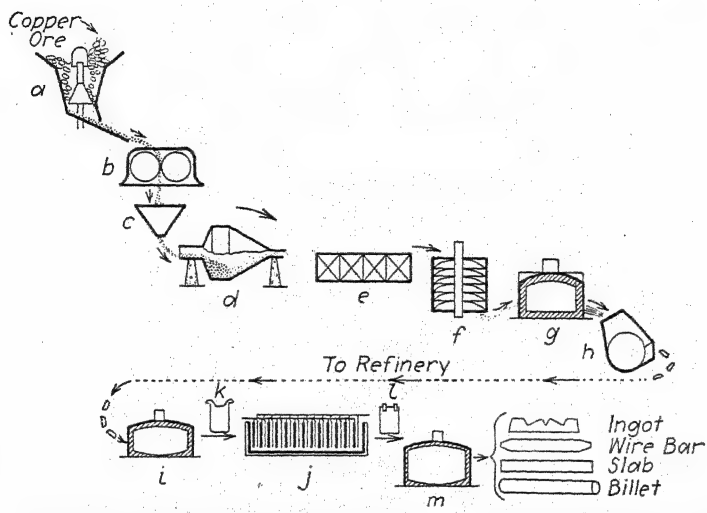

FIG. 229.—Flow sheet on copper refining. *a.* Gyratory ore crusher. *b.* Roll crusher. *c.* Classifier. *d.* Conical ball mill. *e.* Flotation machine. *f.* Roasting furnace. *g.* Reverberatory furnace. *h.* Converter. *i.* Casting furnace. *j.* Electrolytic refining unit. *k.* Anode. *l.* Cathode. *m.* Casting furnace.

Slabs and square cakes of various sizes are used for rolling into sheets. Their sizes depend upon the sizes of the finished product. Circular cakes are used in the manufacture of large, seamless, cylindrical products such as water heaters and tanks. Ingots are used primarily where the copper is melted in crucibles for casting or for making alloys. They have shapes that will most readily fit into crucibles and are cast with notches to facilitate breaking into pieces of the desired quantity. When a bar is composed of two ingots, it is known as an "ingot bar." Billets are

used mostly for seamless copper tubing. They vary in size from 2½ to 8 inches in diameter, from 15 to

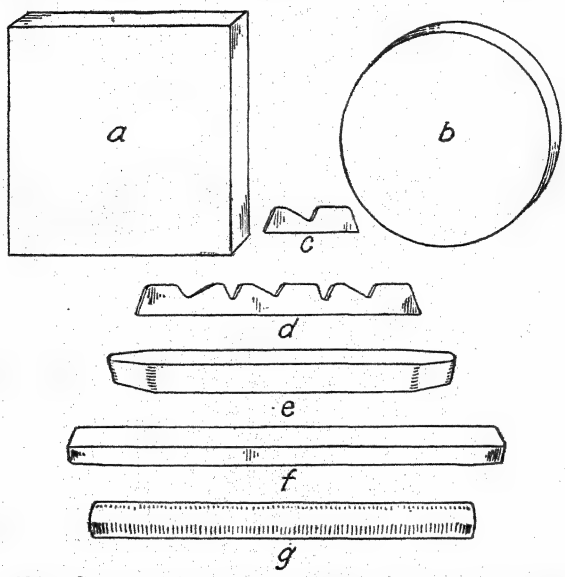

FIG. 230.—Commercial forms of copper. *a*, *b*. Cakes. *c*. Ingot. *d*. Ingot bar. *e*. Wire bar. *f*. Slab. *g*. Billet. (*Courtesy of Anaconda Copper Mining Company.*)

50 inches in length, and from 70 to 600 pounds in weight.

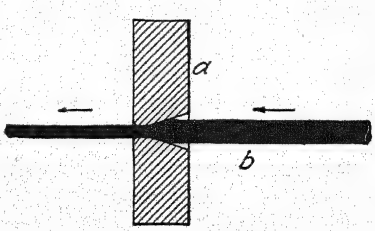

FIG. 231.—Wire drawing. *a*. Die. *b*. Wire.

Secondary Copper.—In addition to the regular supply of new copper directly from the ore, nearly

700,000,000 pounds of so-called "secondary" copper (junk or scrap) are salvaged and used every year. During the World War copper was so high that collecting copper junk became very profitable, and many old kettles and other articles heretofore unnoticed were resurrected and sold for a high price. Thousands of Chinese copper coins were purchased and remelted for their copper content and sold at a profit for making munitions.

Copper Terms

Anaconda—A noted copper-reduction town in Montana.

anode—The positive pole, or terminal, at a gap in an electric circuit.

billet—A round bar of commercial copper generally used for the manufacture of seamless tubing.

blister copper—Copper as it comes from the converter and is ready for casting into anodes for the electrolytic refining process.

blue stone (blue vitriol)—Copper sulphate.

cathode—The negative pole, or terminal, at a gap in an electric circuit.

chalcocite—Copper ore (a sulphide of copper), Cu_2S.

chalcopyrite—A yellowish copper ore sometimes called copper pyrite, $CuFeS_2$.

concentrates—The richer pieces of ore after they have been separated from the poorer.

copper ingots—Notched bars of commercial copper used for casting purposes. The notches are left for convenience in breaking up the bars.

electrolysis—The process of decomposing a chemical compound by passing an electric current through it.

electrolyte—The solution used in the electrolytic process of refining a metal (for copper it is copper sulphate and sulphuric acid).

enargite—Copper ore (a copper arsenic sulphide), Cu_3AsS_4.

flapping—Striking the surface of molten copper with a rabble to increase the surface exposed to the air.

flotation process—The process of concentrating ore by immersing and agitating the powdered materials in an emulsion of oil and water and sometimes chemicals. The richer particles float while the poorer ones sink. (When the process selects one metal from another, it is known as "selective" concentration.)

jig—A machine for concentrating ore by the action of water pulsating in a tank, similar to the jig for separating slate from coal.

leaching—Dissolving copper out of its ore with a sulphuric acid solution.

matte—Crude copper as it comes from the smelting furnace, containing from 38 to 42 per cent copper.

oxidizing—Blowing air through molten copper to remove hydrogen, carbon monoxide, and sulphur compounds.

pine oil—A product obtained by the distillation of pine rosin. See wood turpentine, p. 105.

poling—Burning a log of green wood in molten copper to remove the impurities, especially oxygen.

secondary copper—Copper scrap.

selective flotation—Concentrating by separating one kind of ore from another with a special chemical solution.

slime—The settlings in the bottom of an electrolytic refining tank containing gold, silver, and other impurities.

smelting—See iron smelting, p. 363.

stope—A special type of excavation in a mine for removing ore.

stull—A round timber used to support the sides or back working of a mine.

tailings—The rock left after copper has been removed by concentrating or leaching.

wire bar—Bars of copper somewhat tapered at the ends to facilitate their entering the rolls when being rolled into rods.

Copper Questions

Group I

1. Explain where the word "copper" comes from.

2. Mention some of the evidences we have that copper was used in very early times.

3. Name the common kinds of ore used for copper production.

4. Name the principal copper-producing regions in the United States.

5. Name foreign countries that are large producers of copper.

6. What state leads in the production of copper at the present time?

7. In which state and where is the largest single mine? What is the type of this mine?

8. What is the nature of some of the copper ore found in northern Michigan?

9. What can be said of the Rio Tinto copper mines of Spain?

10. Where are the deepest copper mines at the present time?

11. What is meant by copper-ore concentrates?

12. What is meant by the flotation process? What kind of oil is generally used?

13. What is meant by selective flotation?

14. What is meant by tailings? How are they treated to recover copper?

15. What is blister copper, and how is it obtained?

16. What is meant by electrolysis; an electrolyte; slime?

17. Give the size and shape of the anode, also the cathode.

18. How are metals recovered from the slime?

19. Explain the meaning and purpose of poling.

20. What special quality does copper possess that makes it possible to draw it into wire? Name the five general steps in the refining of cathode copper.

Group II

21. Name the two general principles upon which copper-ore concentrating is based.

22. What is copper matte? About what percentage of copper does it contain? What are some of the impurities? What would make these impurities vary?

23. Of what use is the converter? How does the converter for copper differ from the Bessemer converter for steel?

24. Why are tanks for electrolytic refining made of wood or cement?

25. What kind of current is required for electrolytic refining? Explain your answer.

26. Why is green wood used for poling?

27. Mention an Eastern city where a large copper-refining plant is located.

28. Of what importance is the copper industry to radio?

29. What is meant by working ore with copper as a by-product?

30. Why is it impracticable to use the blast furnace for smelting copper-ore concentrates?

31. What evidence do we have that copper was mined and used by the Indians before the white man came?

32. Give reasons why copper is especially good for telegraph and telephone wire.

33. Give reasons for casting commercial copper into various forms.

34. Mention some important qualities that copper possesses which make it suitable for water boilers.

ALUMINUM

Aluminum is a bluish-white metal, malleable, ductile, and light of weight, being about one-third as heavy as steel. It is the most abundant metal in the earth's crust and stands third among the elements, being surpassed only by oxygen and silicon. It is about twice as abundant as iron. Although widely distributed in clay rocks and other minerals it is obtained in commercial quantities at the present time only from a special ore known as bauxite.

Deposits of Bauxite.—Bauxite ore is widely distributed but not extensive in any one locality. Like other ores, it varies in quality; and not all deposits are pure enough for aluminum production. The principal commercial deposits at the present time are in North America, South America, and Europe. France has the largest and richest deposits and furnishes the bulk of all high-grade bauxite used in European countries. The ore derives its name from the town of Baux, France.

The principal deposits in the United States are in Arkansas, Alabama, Georgia, Tennessee, and Mississippi. Considerable quantities are also imported into the United States from the British and Dutch Guianas. The first commercial ore mined in this country was in Georgia, but at the present time Arkansas is the principal state furnishing bauxite for the production of aluminum.

Historical Sketch.—As far back as 1825 Oersted, a Danish scientist, succeeded in extracting a small amount of aluminum from aluminum chloride, and about a quarter of a century later Sainte-Claire Deville, a French chemist, developed the first practical process for the production of aluminum. Production of the metal on a large commercial scale, however, is of comparatively recent date. As late as 1850 it was regarded as a rare metal, and the price was over $500 per pound. In 1886 it had fallen to $8.00 per pound; in 1892 it was down to 60 cents; and at the present time (1940) it is around 20 cents. This tremendous drop in price is due largely to research

and the application of scientific principles to methods of production.

Several processes for the production of aluminum had been developed but with uncertain results, until the Hall-Héroult electrolytic process of extracting the metal from purified bauxite (aluminum oxide) came out in 1886. Charles M. Hall, a young graduate of Oberlin (Ohio) College, working in his father's woodshed with some wires, some chemicals, and a string of batteries, succeeded in producing a small lump of metallic aluminum. The secret was out, and the principle discovered by Hall is the same one employed in the great aluminum industry of today. It appears that at about the same time that Hall discovered his process, Héroult, of France, discovered the same principle; hence we have the Hall-Héroult process.

Bayer Purification Process.—As ordinary bauxite cannot be used directly for electrolytic reduction because of its impurities, the whole process divides into two branches: (1) purification of the ore to produce pure alumina and (2) reduction of the alumina by electrolysis. Several processes of purifying the ore have been developed, but the one generally used at the present time is known as the "Bayer" process, in which the aluminum oxide is dissolved out of the bauxite by means of caustic soda, filtered to remove impurities, reprecipitated as aluminum hydrate, and calcined to form pure alumina (aluminum oxide, Al_2O_3).

Hall-Héroult Electrolytic Process.—A common electrolytic cell used in the Hall process consists of a rectangular steel box about 8 feet long by 4 or 5 feet

wide by 2 feet deep lined with refractory material (Fig. 232). (A series of cells is known as a battery.) Inside the refractory lining is a second lining or baked-in carbon mixture which forms the cathode. Carbon electrodes, supplied with current from above, project downward into the box and form the anodes. A batch of cryolite is introduced and fuses when the

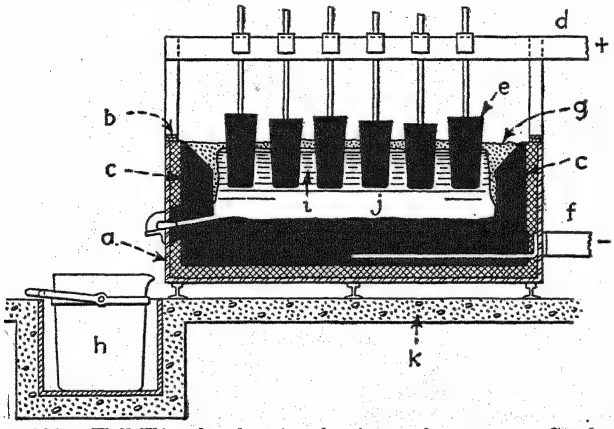

FIG. 232.—Hall-Héroult electric aluminum furnace. *a.* Steel shell. *b.* Electric insulation. *c.* Carbon lining. *d.* Bus bar. *e.* Carbon (positive) electrodes. *f.* Negative connection (collecting plate). *g.* Frozen crust of electrolyte and aluminum. *h.* Ladle. *i.* Molten electrolyte. *j.* Molten aluminum. *k.* Concrete floor. (*Courtesy of Aluminum Co. of America.*)

current is turned on. Alumina (refined bauxite) is stirred in and dissolves. The passage of an electric current through the solution separates the aluminum from the oxygen and deposits it on the bottom in a molten state, while the oxygen combines to make carbon monoxide and burns off as a gas. Fresh alumina is added from time to time, and the metal is drawn from the bottom of the cell every day or two,

thus keeping the process continuous. The amount of current may vary from 8,000 to 30,000 amperes, and the temperature required is about 1000°C. The type of furnace described will produce about 200 pounds of aluminum every twenty-four hours. A series of these furnaces is called a battery.

Cryolite.—Cryolite occurs in commercial quantity and is mined at only one place—Ivigtut, Greenland. The greater part of the product is shipped to Copenhagen; the remainder is exported to the United States, from which country some is reexported to Canada. Most of the cryolite shipped to the United States is used in the metallurgy of aluminum and in making opaque glass. It is quite possible, however, to make a synthetic cryolite which is the chemical equivalent of natural cryolite as far as the production of aluminum is concerned, and either synthetic cryolite, produced in the United States, or natural cryolite may be employed in the electrolytic reduction of aluminum.

In addition to primary aluminum produced from bauxite, a large amount of scrap or secondary metal is recovered. So important is this branch of the industry that separate firms have been organized for handling the product.

Commercial Forms and Uses.—Pure aluminum, like pure gold, is too soft for practical purposes, but in alloyed form it has many applications. Among the common elements used for alloying are copper, silicon, magnesium, manganese, zinc, and nickel. The alloys divide into two general classes: casting alloys and wrought alloys. Some of the more common com-

mercial forms are pig; ingot; plate, sheet, and foil; bar; wire and rod; seamless tubing; moulding and structural shapes, both extruded and rolled; screw-machine products; stampings; forgings; and sand, die, and permanent castings, and pigment for paint. Some of the more common aluminum articles are pistons, connecting rods, crank cases, and oil pans for automobiles; truck bodies; bus bodies; electrical conductors; street-cars and railway coaches; ornamental work; sheet-metal work; chairs; cooking utensils; and airplane parts, without which the development of the aeronautical industry to its present status would not have been possible. Recently a new floor system of strong aluminum alloys was installed on the Smithfield Street Bridge at Pittsburgh, Pa., eliminating practically 750 tons of dead weight as compared with the use of other metal.

Aluminum Terms

alumina—Aluminum oxide.

aluminum bronze—Finely divided metallic aluminum mixed with a vehicle (oil) into a paint for painting metallic surfaces.

bauxite—See abrasives, pp. 214, 267.

cryolite—A fusible mineral, found principally in Greenland, used in its molten state for the bath or electrolyte in the production of aluminum by the Hall process.

ductile—The property of being malleable, able to be drawn out into wire or other forms.

pig aluminum—Raw aluminum cast into pig form as it comes from the furnace.

precipitate—To separate a solid form from a solution by chemical means.

synthetic cryolite—Cryolite produced by chemical reaction.

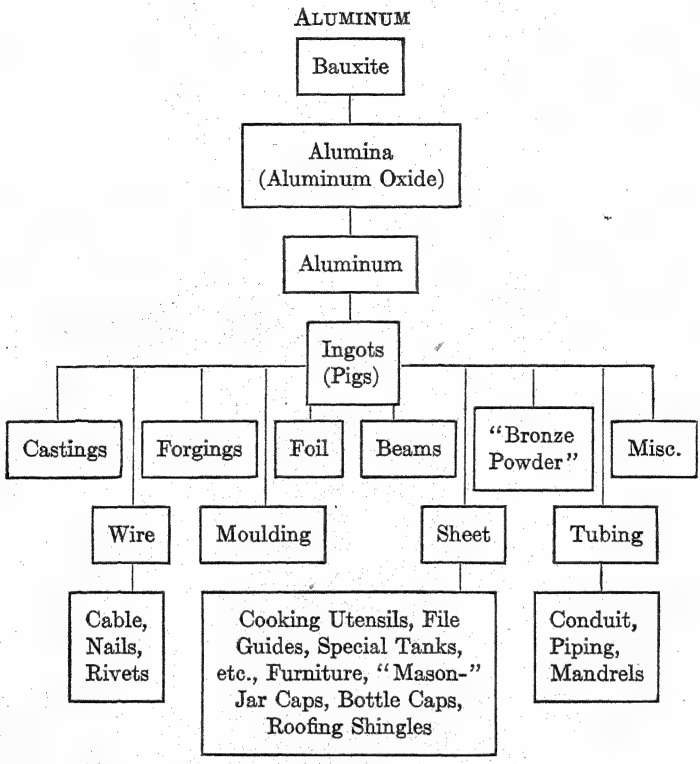

FIG. 232*a*.

Aluminum Questions

GROUP I

1. What is bauxite?
2. Where does bauxite get its name?
3. In what countries are the principal deposits of bauxite? Which of the states produces the largest amount?
4. From what South American countries do we import bauxite?
5. Why is raw bauxite unsuitable for aluminum production?
6. Describe briefly the Bayer process of treating bauxite.
7. Describe briefly the Hall process of producing aluminum.

8. Why is the Hall process sometimes called the Hall-Héroult process?

9. Who was Charles Hall, and what was he doing when he discovered the process of producing aluminum?

10. What is cryolite, and for what purpose is it used in the production of aluminum? From what country is it obtained?

11. What is meant by an aluminum alloy? What is aluminum bronze?

12. What special quality does aluminum have that makes it possible to draw it into wire?

13. What is the most abundant element in the earth's crust?

Group II

14. What is alumina? How does it differ from aluminum?

15. Is the Hall process a fusion or an electric process? Explain your answer.

16. Why is an aluminum furnace lined with carbon?

17. Name some qualities that distinguish aluminum from steel.

18. In what special way has aluminum assisted in aviation?

19. Give reasons why aluminum is used extensively for cooking utensils.

20. Where are aluminum plants likely to be located?

21. Explain why aluminum is valuable for electrical work.

22. Mention places where you have seen aluminum used in automobile construction.

23. What are some of the special characteristics of aluminum?

24. What is meant by "synthetic" cryolite?

LEAD, TIN, AND ZINC

Lead is a soft, bluish, ductile, heavy metal. Like copper it was known and used in very ancient times, not only alone but combined with other metals to form alloys.

Lead Ore.—For the most part, lead is obtained from an ore known as "galena," a lead sulphide. As

a rule, it is associated with zinc, copper, silver, arsenic, iron, and sometimes gold and other metals. Practically every country has at least small deposits of lead ore. At the present time the main developments from which the greater percentage of the world's supply is obtained are in the United States. Next in importance comes Mexico, followed by Australia, Canada, Spain, Germany, India, Italy, and Tunis. In this country the main producing sections are southern Missouri, Idaho, Kansas, Oklahoma, Utah, Colorado, and Montana (Fig. 220).

Mining and Smelting or Refining.—Mining lead does not differ in its essentials from mining copper and other non-ferrous metal ores. The rock is blasted loose and brought to the surface and concentrated in practically the same manner as copper ore. As a matter of fact, a large percentage of the world's present supply of lead and zinc is obtained from tailings thrown away or from ores that could not be mined profitably before the flotation process of concentrating was developed. (Here is another striking example of the utilization of waste material by the application of advanced scientific principles.) As a rule, the concentrates are calcined to remove the sulphur and sintered to melt them together before being smelted. They are then mixed with flux and coke and smelted in a blast furnace in much the same manner as iron ore. The product is known as "matte," or "base bullion," and generally contains other metals such as gold, silver, zinc, arsenic, and copper. Lead bullion is sufficiently pure for some

kinds of work, but in the production of white lead and for other special purposes it must be further refined. Among the most important of the refining processes is "liquation," or the use of the principle of the difference in the temperature of the fusing points of various metals. In this process the bullion is melted, and the temperature reduced to below the melting point of copper. The copper, being lighter and having a higher fusing point than the lead, rises to the top and solidifies and can be removed. The temperature is raised and the molten lead agitated. Lime is added, which removes the arsenic and antimony, and the oxygen of the air removes iron and other metals that can be oxidized. The product now may contain a small amount of precious metals which can be removed by desilverizing. In this process zinc is added to the bath, which unites with the precious metals and brings them to the top where they can be removed. The precious metals are then recovered by vaporizing off the zinc. Lead refined by this process is sometimes over 99.99 per cent pure. It can also be refined by the process of electrolysis much in the same manner as copper. In the process, base bullion is used for the anodes, and sheets of pure lead for the cathodes. The electrolyte is lead fluosilicate instead of copper sulphate and sulphuric acid.

Common Uses of Lead.—In its metallic form lead is used in sheets, pipes, cable coverings, and foil. It is made into battery plates, shot, bullets, and many other small cast articles. It is alloyed with tin to make solder and with antimony and tin to make bear-

ing metal and type metal. A large percentage is oxidized to white lead, red lead, and litharge. It is also used extensively in enamels, glass, pottery, rubber, and varnish. It is especially serviceable in tank linings, for pipes, and for tubes where the resistance to the attack of acids must be withstood.

Tin.—So-called "tin" containers such as tomato cans, corn cans, oil cans, and the like, are very common. The metal is especially valuable for these articles because of its acid-resisting qualities. As a matter of fact, however, very little tin enters into the construction of these commodities. They are generally made of soft sheet steel washed or coated with tin on the surface.

Tin-ore Deposits.—The main workable deposits of tin ore at the present time are in the Malay Peninsula, from which over 25 per cent of the world's supply is obtained. It is also mined in Bolivia; southern China; Sumatra; Cornwall, England; Australia; South Africa; and Alaska. The principal kind of ore is known as "cassiterite," SnO_2, and is found largely in alluvial deposits, although there are veins, or lode mines, in solid rocks sometimes deep in the earth. When the alluvial deposits are worked, the placer method of mining is generally used. In some instances the gravel produces only a pound of tin to the cubic yard, but under favorable conditions with even this small percentage the ore can be worked with profit.

Like other non-ferrous metal ores, tin ore must be concentrated before it can be smelted with profit. The processes involved in concentrating do not differ

in principle from those used for other metals. Sometimes concentrates with a percentage of tin from 50 to 70 per cent can be obtained, depending upon the locality in which the ore is found.

Roasting and Smelting.—Tin concentrates are prepared for smelting according to the impurities that they contain. When sulphur is present they are first roasted to remove this element. In the roasting process other impurities as well as some tin are oxidized and washed out by acid and hot-water treatment. The object of roasting is to have the concentrates as free as possible from other metal impurities before they are sent to the smelting furnaces. Furnaces for roasting differ considerably in their designs, but in all cases the same purpose is served. The sulphur must be removed to avoid a great loss of tin in the smelting process. As the tin in the concentrates is in the form of oxide of tin, it must be smelted in a reducing furnace in the presence of carbon as a flux. A reverberatory furnace is generally employed for smelting, using oil, coal, or gas for fuel, and a temperature of from 2500 to 3000°F. is required. The time required for smelting varies from ten to twelve hours. In order to release as much tin as possible from the concentrates, a flux of limestone is also used in the smelting process, the amount depending upon the silica and other impurities present. As considerable tin passes off by volatilization during smelting, the waste-gas flues are connected with a fume-collecting system which recovers this tin and returns it to the smelter.

Refining.—The tin bullion, or matte, is finally sent through a refining and cleaning process to remove the remaining impurities. Large kettles are used for refining, the molten tin being agitated in these kettles by air introduced from underneath. This agitation causes the impurities to rise to the surface, from which they can be easily removed. The refined tin is then cast into pigs of about 100-pound weight and is ready for the market.

Uses of Tin.—As has been suggested, tin is used largely for tin plate for containers and other commodities. It is also used for roofing, flashing, and gutters where its non-corrosive qualities make it valuable. It is alloyed with copper to make bronze, with lead to make solder and bearing metals, and with antimony for type metal and other alloys. It is made into foil, used for collapsible tubes for toilet articles, and introduced into silk cloth to give it weight and rustle.

Zinc, Historical.—Relics of brass and other metal alloys found in ancient ruins prove that zinc was known and used at a very early date. We also have reference to its use in the Bible and other historical writings.

Zinc-ore Deposits.—Zinc ores are distributed widely, especially in North America and Europe, and, as a rule, are associated with lead and other metals. In the United States the main deposits are in the Joplin district of Missouri, Kansas, and Oklahoma, in northern New Jersey, Montana, Wisconsin, and Colorado (Fig. 220); and in Europe in upper Silesia, Spain, and the island of Sardinia. It

is also mined to considerable extent in Australia, Sweden, southern China, and Japan.

Distillation.—Mining and concentrating zinc ores do not differ materially from mining and concentrating copper and other non-ferrous ores. When the ore contains considerable iron, however, as in northern

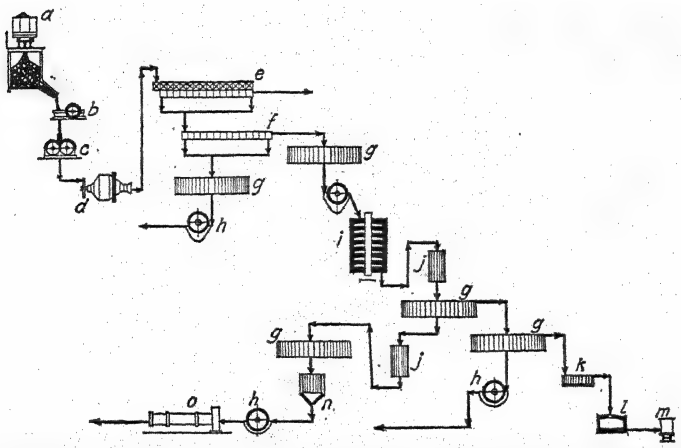

FIG. 233.—Flow sheet for zinc refining. *a*. Car of ore. *b*. Jaw crusher. *c*. Roll crusher. *d*. Conical ball mill. *e*. Flotation machine. *f*. Flotation machine. *g*. Dorr thickeners. *h*. Filter. *i*. Roasting furnace. *j*. Pachuca tank. *k*. Electrolytic cells. *l*. Casting furnace. *m*. Car. *n*. Filter. *o*. Drier.

New Jersey, the iron is generally removed by an electric magnet. But for the most part some form of flotation process is used. In extracting the metal from the concentrates three general processes are in use: (1) ordinary distillation, (2) electrothermal distillation, and (3) electrochemical treatment. The apparatus for the ordinary distillation process consists, in general, of a special furnace supplied with about eighty or

ninety small clay retorts of about eighty pounds charge capacity each.

A mixture of calcined ore and coal or coke is charged into the retorts, and the temperature raised until the zinc is melted and boils and passes off in a vapor. The vapor is then condensed into metallic zinc in a special condensing chamber and is ready for casting into commercial forms. The residue left in the retorts is worked over to recover copper, silver, or any other metal that it may contain in paying quantities. In the electrothermal process an electric furnace is used for vaporizing, but the principle involved is practically the same as that for the ordinary distillation process. The cost of operation, however, prohibits the use of the electric furnace except in places where electricity is comparatively cheap. At the present time its use is confined almost entirely to Sweden where only a small percentage of the world's supply of zinc is obtained.

Electrochemical Refining.—The electrochemical treatment process is divided into two general parts: leaching, and separating the metallic zinc from the solution. After the concentrates are roasted to drive off the water and as much sulphur and other impurities as possible, they are treated with a sulphuric acid solution which dissolves the zinc and precipitates the iron, copper, and other metals. The solution is now clarified and run into special lead-lined electrolyzing tanks for separating. Anodes of lead and cathodes of thin sheets of aluminum are used in the electrolytic process. When the current is turned on, the zinc

separates from the solution, and is deposited on the aluminum cathodes from which it can be peeled off and is ready to be cast into commercial forms. The acid solution, now separated from its zinc content, goes back and is used over again for leaching the concentrates.

Some common uses for zinc are for alloying with copper to make brass, for galvanizing, for sheets for various purposes, for zinc oxide for paint, and for desilvering lead.

NON-FERROUS ALLOYS

As in the case of steel alloys, there are countless combinations of elements composing non-ferrous alloys, but only a comparatively small number are in common use. In each case the alloys generally contain traces of other elements besides those mentioned, but these are of no importance to the quality of the metal. The following are a few of the more important of these alloys:

Carboloy.—Carboloy is the trade name for a new commercial alloy. It is a compound of tungsten, carbon, and cobalt, produced by subjecting an intimate mixture of these ingredients to enormous pressure at a temperature below the fusing point. The metal is more than twice as hard as steel and from twenty to seventy-five times as durable. It is especially valuable for high-speed cutting tools. One of its very important features is that it will retain a cutting edge at a bright-red heat.

Monel Metal.—Monel metal is an alloy of 68 per cent nickel, 28 per cent copper, and traces of other

elements. It is tough, strong, and has exceptional non-corrodible qualities. Because of this last quality it is valuable for valves, pipes, tanks, propeller shafts, restaurant and hospital equipment, and other articles that come into contact with liquids, acids, and steam.

Monel "Seventy" Alloy.—This alloy is composed of 70 per cent nickel compounded with copper and manganese. It is also noted for its non-corrodible qualities and is used in dye works, acid works, and other places where this quality is of special value. Its qualities and uses are practically the same as those for monel metal.

Brass.—Brass is an alloy of copper and zinc and ranges in composition from 60 per cent copper and 40 per cent zinc to 95 per cent copper and 5 per cent zinc. The more common brasses contain from 55 to 70 per cent copper. The uses of brass are too numerous and too well known to need enumerating.

Bronze.—Bronze is an alloy of copper and tin and ranges in composition from 80 per cent copper and 20 per cent tin to 95 per cent copper and 5 per cent tin. When it contains about 1 per cent phosphorus it is known as "phosphor bronze" and has special strength and non-corrosive qualities. It is used extensively in marine-boiler tubes, condensers, pump rods, vats, tubs, stills, and other articles exposed to the action of liquids. Its use as a metal for statuary exposed to the weather is well known.

German Silver.—So-called "German silver" is an alloy generally of 60 per cent copper, 20 per cent nickel, and 20 per cent zinc. It is used largely for musical instruments, ornaments, and resistance wire.

Dowmetal.—Dowmetal is the trade name applied to a group of magnesium-base alloys. Their general composition ranges from 85 to 98.5 per cent magnesium combined with various percentages of aluminum and manganese and sometimes cadmium and copper. Dowmetal is the lightest general structural metal known, having a specific gravity of 1.80, or about one-fifth the weight of copper. It is soft, strong, and ductile and can be rolled, forged, drawn, or cast into form. Its principal uses are for airplane, automobile, and other machine parts, for tubing, truck bodies, flasks, core boxes, and patterns in foundries, and for household utilities, as vacuum cleaners, and floor polishers.

Stellite.—Stellite is an alloy containing about 45 per cent cobalt, 30 per cent chromium, and 15 per cent tungsten with small amounts of manganese, silicon, iron, and carbon. It is very hard and requires no heat treatment for tempering. It finds its use largely as tips for tools and facing for dies for automobile construction.

Cemented Tungsten Carbide.—This is a sintered alloy product composed of from 80 to 97 per cent tungsten carbide, the remainder being cobalt. It is very hard and, like stellite, is used for tool tips and die facings for automobile construction. Because of the high cost of these metals only small amounts are welded to common steel-tool shanks for cutting edges and mounted on the cheaper material for die facings.

Aluminum Alloys.—Only a few of the aluminum alloys can be considered in this connection. The principal alloying elements are copper, silicon, manga-

WROUGHT-ALUMINUM ALLOYS

Alloy	Per cent				
	Copper	Manganese	Magnesium	Silicon	Aluminum (minimum)
17S	4.0	0.5	0.5	...	92.0
A17S	2.5	...	0.3	...	95.0
B17S	3.5	...	0.3	...	94.0
25S	4.5	0.8	...	0.8	92.0
51S	...	...	0.6	1.0	96.5
195	4.5	...	...	...	93.0

CAST-ALUMINUM ALLOYS

Number[1]	Copper	Zinc	Silicon, manganese, iron, tin	Other elements
30	7 to 8.50	0.20	1.70	0
31	2.25 to 3.25	12.50 to 14.40	1.70	0
31A	2.0 to 3.50	9.0 to 11.50	1.25 to 1.75	0
32	11.0 to 13.50	0.2	1.70	0
38	4.0 to 5.0	0.25	Silicon, 1.20	Iron, 1.20

[1] The number designations are after the Society of Automotive Engineers.

nese, magnesium, zinc, nickel, and iron. Duralumin is the name often applied to a class of light alloys that are susceptible to heat treatment and aging

phenomenon. They contain about 4 per cent copper and show small percentages of other elements, including magnesium, the remainder being aluminum.

WEIGHTS PER CUBIC FOOT AND FUSING POINTS OF COMMON METALS

Metal	Weight per cubic foot, pounds	Fusing point, °F.
Aluminum	165	1217
Antimony	418	986
Alumina	139	3722
Brass, common	534	1870
Cast Iron, white	450	2074
gray	442	2230
Copper	556	1981
Kaolin	....	3191
Lead	710	621
Gold	1205	1945
Magnesia	108	5072
Manganese Bronze	554	1600
Nickel	537	2646
Platinum	1330	3191
Silver	656	1760
Steel	636	2372
Tin	459	449
Wrought Iron	485	2732
Zinc	440	782

The brief tables on page 502 will serve to give an idea of a few typical aluminum alloys. The missing percentage is aluminum and slight traces of other elements that do not impair the quality of the metal.

Non-ferrous and Non-ferrous-alloy Terms

antimony—A non-ferrous metallic element.

babbitt metal—A composition of 89 per cent tin, 8 per cent antimony, and 3 per cent copper or 80 per cent lead and 20 per cent antimony. It is used mostly for bearings for shafts.

base bullion—Crude lead, the first product from the ore.

bell metal—A composition of 75 per cent copper and 25 per cent tin used for bells.

cassiterite—The principal tin ore, tin oxide, SnO_2.

casting alloys—Alloys made for castings.

coinage metal—Copper cents, 95 per cent copper, 4 per cent tin, and 1 per cent zinc; five-cent pieces, 75 per cent copper and 25 per cent nickel.

galena—Lead sulphide ore, PbS, the principal ore from which lead is obtained.

liquation—Separating the elements of a metallic alloy by the use of the principle of the differences in their fusing points.

pewter—A metal of 80 per cent tin, 18 per cent lead, and 2 per cent antimony; used for plates, mugs, etc.

solder—Low melting, 66 per cent tin and 34 per cent lead; common solder 50 per cent tin and 50 per cent lead.

type metal—5 to 20 per cent tin, 25 to 30 per cent antimony, sometimes a small per cent of copper, the remainder lead.

wrought alloys—Alloys made malleable for working cold.

Non-ferrous and Non-ferrous-alloy Questions

Group I

1. What are the principal qualities of lead?

2. Name the lead-producing countries of the world in the order of their importance.

3. Name the principal lead-producing states.

4. What is the principal source of lead at the present time?

5. How are lead ores generally treated before they are smelted?

6. What does base bullion generally contain besides lead?

7. Name other ways in which lead can be refined besides liquation.

8. Of what are the so-called tin containers mostly constructed?

9. Why is tin especially good for containers for fruit and vegetables?

10. What type of furnace is generally used for lead smelting? What is the fuel used, and about what temperature is required?

11. How is base bullion refined?

12. Name the main zinc deposits in the world. Name the main zinc deposits in the United States.

13. How is iron removed from zinc concentrates?

14. Describe the leaching process of extracting zinc from its ore.

15. What is the residue left in the retort when zinc is smelted?

16. Of what is carboloy composed, and what makes it especially good for tool points?

17. What special qualities does bronze have that make it good for marine-boiler tubes, valves, condensing worms, etc.?

18. What special quality does dowmetal have that makes it good for airplane construction?

19. Name other alloys that are used for machine-tool tips aside from carboloy.

Group II

20. What has made it profitable to work over lead and zinc ores (tailings) that were formerly thrown away as worthless.

21. How can we separate the elements copper and lead in an alloy of these metals?

22. Give two reasons why lead is especially good for tank linings.

23. Why are so-called tin containers made mostly of steel?

24. Explain the process of placer mining.

25. When a metallic oxide ore is smelted what element must be employed to remove the oxygen?

26. In what respect does the production of zinc from the ore resemble wood distillation?

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CHAPTER V

MISCELLANEOUS

RUBBER

Historical Sketch.—It is reported that when Columbus visited South America he found the natives playing with a ball that had remarkable resilient qualities. They had made it from the juice of a tree. He was much interested and took samples of the material back to Spain, but little attention was given to the matter at the time. When the Portuguese began to colonize Brazil, attempts were made to commercialize the product but with little success.

About 1730 the French Academy of Science became interested in the subject and sent explorers into the Amazon Valley to make investigations. The expedition reported that the material came from the juice (*latex*, the Spanish word for "milk") of a tree known as the "hevea" and that "there flowed from the bark of this tree a liquor which hardened and blackened in the air." They also found the natives using the material for coating, or waterproofing, for cloth and making bottles, pouches, and a few other articles, some of which afterward found their way to Europe.

As early as 1800 the Brazilians were manufacturing and shipping a few rubber articles to North American ports; and clipper ships from New England occasion-

ally brought back lumps of crude rubber as ballast. About 1820 Mackintosh, a Scotchman, invented a process of waterproofing cloth by inserting a thin sheet of rubber between two layers of cotton fabric. This did not prove altogether satisfactory, because the articles made from the cloth were soft and sticky in the hot weather of the summer and hard with a tendency to crack in the cold weather.

Priestley, the famous English chemist, did some experimenting with the gum but seemed to have reached no more important results than to discover that it would rub out (erase) pencil marks. Therefore he gave it the name of "rubber." (The name "India" rubber came from the fact that the gum was supposed to have first been discovered in India.)

Work of Goodyear.—It was not until over a hundred years after the French Academy of Science had made its investigation that the rubber industry began to give promise of importance. It remained for Charles Goodyear, a Connecticut Yankee, to discover a process by which this was made possible.

Goodyear was a small hardware merchant with an inventive turn of mind which often interfered with his regular business. He became intensely interested in the subject of rubber and strove to produce an article that would be serviceable under all ordinary changes of temperature. For several years he worked indefatigably on the subject in spite of poor health, poverty, and the jeers of his friends. When asked how Goodyear could be recognized, one of his friends replied: "If you see a man with an India rubber coat,

India rubber shoes, and an India rubber purse with nothing in it—that is Goodyear." But these things did not move Goodyear from his purpose. Still he worked on. The story goes that while experimenting one day with some rubber and sulphur he dropped the mixture on a hot stove. The mass melted and ran together, and when it was cooled it was found to be a tough, doughlike substance that was not affected by the ordinary changes of temperature. This was in the year 1839. The secret was out. Goodyear had won. Daniel Webster, in defending Goodyear in a lawsuit in after years, remarked that the name of Goodyear would be held in history in the same esteem as that of Fulton and Watt.

Goodyear called his process "vulcanizing" after the Greek god of fire Vulcan, and to the product he gave the name of "gum elastic," a name which is still applied in part in certain localities to rubber shoes and boots, as "gum" shoes and "gum" boots. Soon after Goodyear's discovery, rubber factories began to spring up in the New England states; and as early as 1844 rubber shoes and other rubber articles were exported to England and elsewhere. For many years the industry was confined to the manufacture of footwear, coats, and a few minor articles. But increasing demands for railroad work, electrical appliances, and general rubber utilities caused the industry to branch out in other directions. The great impetus to the industry, however, came with the advent of the automobile, which requires more rubber than all other rubber-using industries combined.

Sources of Raw Rubber.—As early as the middle of the past century the question of raw-rubber supply began to come to the front. Up to that time practically the entire supply had come from the wild hevea trees of the Amazon Valley. But the rapidly increasing demand as well as the increasing difficulty and cost of collecting and shipping the product from that section aroused manufacturers to seek other sources. Rubber-producing trees were known to grow in other parts of the world, but the quantity and the quality of their latex could not measure up to that of the hevea tree of the Amazon Valley. Suggestions were made that experiments be tried in growing the hevea trees in other parts of the world, but the Brazilian government was jealous of its monopoly and carefully guarded all its territory to prevent any rubber-tree seeds from leaving the country.

About 1876, however, Henry Wickham, an Englishman, succeeded in obtaining some hevea-tree seeds, which he took to England and had planted in the Kew Gardens. The seeds germinated rapidly in their new environment, and in time seedlings were transplanted to the island of Ceylon. Here the trees did exceptionally well and in a few years had so multiplied that they could be distributed elsewhere in the East Indies. From this small beginning the rubber-plantation industry has grown until at the present time there are over 600,000,000 hevea trees under cultivation in that part of the world, covering an aggregate area of from 6,000 to 8,000 square miles. (It is interesting to learn that a considerable percentage

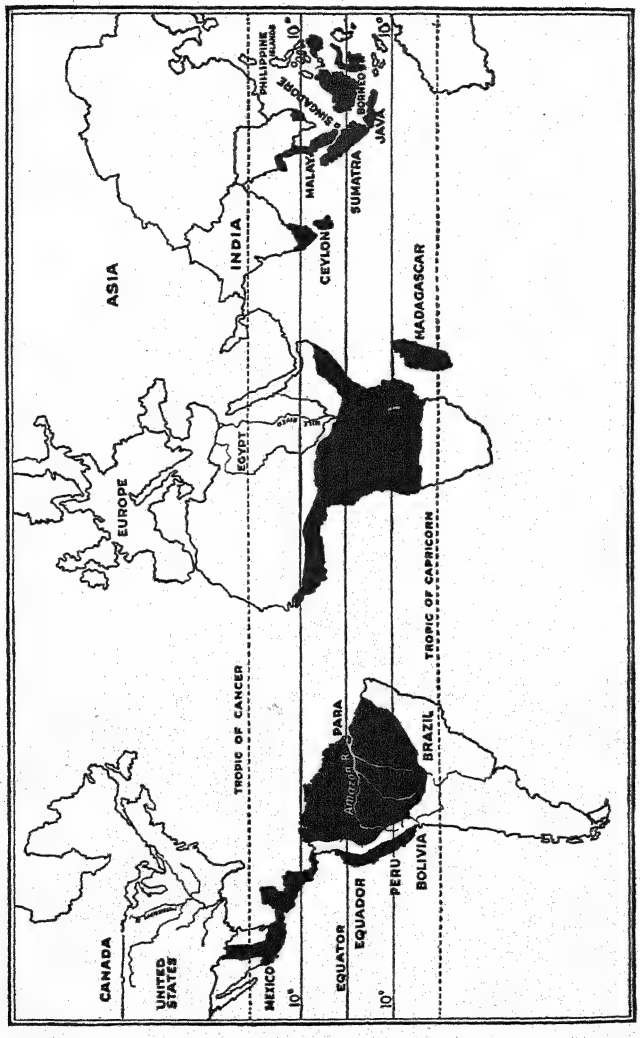

Fig. 234.—Rubber belt around the world.

of the East India rubber plantations are owned and controlled by American interests.) Rubber trees require a hot, wet climate, and for this reason the plantations were located in the lowlands and jungles of the tropics. These lowlands and jungles are found principally in an area of about ten degrees on either side of the equator, which is known as the "rubber belt around the world" (Fig. 234).

Hevea trees are very rapid growers under favorable conditions. Some of them reach a diameter of four feet in forty years. They begin to produce rubber in about five years and gradually increase the yield as they get older. Just how long this will continue has never been determined, as the oldest trees of Ceylon, planted over fifty years ago, have not yet begun to show signs of decreasing their yield.

At the present time it is estimated that less than 10 per cent of the world's supply of rubber comes from the wild trees of the Amazon Valley. This proportion will naturally grow less as new plantations are developed. An American syndicate has recently acquired a large tract of land in the jungles of Liberia for the purpose of growing rubber-tree plantations. The possibilities for plantation rubber growing in the Amazon Valley are also promising. It is probably only a matter of a few years when the hevea tree will be seen growing in large plantations in its own native country. The chief obstacle is the cost of labor as compared with very cheap labor in the East. There are many plants and trees that contain juices capable of producing rubber, but the quantity in most cases

is so small and the quality so inferior that they do not pay for working. Our own milkweed and stag-horn sumac are examples of such plants. Rubber is also obtained in Mexico, Venezuela, Peru, Ecuador, and Africa, but the amounts from these sources are insignificant compared to that obtained from the East India plantations.

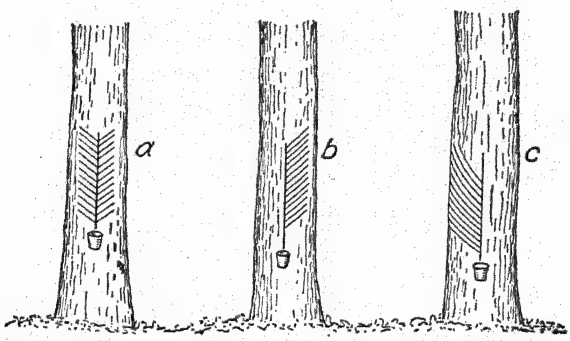

FIG. 235.—Rubber-tree tapping. *a.* Herringbone method. *b.* Half herringbone method. *c.* Spiral method.

Tapping Rubber Trees.—The latex of the rubber tree is not a sap but a juice found between the outer and inner barks. There are several methods of obtaining this from the trees, among which are spiral tapping, herringbone tapping, half-herringbone tapping, and others (Fig. 235). In spiral tapping a groove is cut in the bark in a spiral manner about one-third of the way around the tree. At the bottom end of the groove a small porcelain or glass cup is affixed to catch the latex as it runs down. Each succeeding morning the tapper widens the groove by slicing off a thin layer of bark from the edge of the cut,

which exposes a fresh surface out of which the latex can flow freely. Care must be exercised in tapping not to cut into the wood, else the tree would be injured. In the herringbone method, a central vertical groove is made in the bark extending up about four feet from the ground. Slanting lateral cuts are made from the groove on either side, giving the appearance of the backbone and the ribs of a herring. The latex runs from the lateral grooves into the central groove and so on down into a cup attached at its lower end. In the half-herringbone method, lateral cuts are made on one side of the vertical groove only. Still another method is to cut the bark on a slant about halfway round the tree. Of course the object in all methods is to do the tapping in such a manner as to secure the maximum amount of latex without injury to the trees. Tapping if properly done does not seem to be injurious but, on the contrary, is beneficial. As soon as the latex ceases to flow, nature heals the wounds.

Coagulating.—After the latex is collected, it is generally coagulated, separated from its water, and hardened. In the wild-rubber regions this branch of the industry is accomplished by smoking it over a fire of palm nuts (Fig. 236). A paddle is dipped into the liquid and held over the fire until the film is hardened. This is repeated until a large ball, or biscuit, is collected. Rubber coagulated by this method is dark colored, of lower moisture content, and contains more or less foreign matter, although as a rule it is of high quality.

The more modern method of coagulating, and the one used mostly for plantation rubber, is to treat the latex with weak acetic acid in porcelain tubs. This process removes most of the water and leaves the rubber in a doughlike mass that can be easily rolled, smoked, dried, or otherwise prepared for the market. (A drop of vinegar in a spoonful of milk will cause

FIG. 236.—Coagulating latex, over smoke. *a*. Fire of nut shells. *b*. Paddle. *c*. Lump of rubber.

the milk to act much in the same manner as latex treated with acetic acid.) From the coagulating vats the rubber is sent through rolls to remove the water and work the mass into sheets. If the product is to be plain white crêpe, the sheets are sent immediately to the drying room. If ribbed, smoked sheet is desired, the sheets are passed through rolls having ridges on their surfaces and then hung in a drying room for several days and fumigated with smoke, which gives them their reddish color and hamlike odor.

(One large company has developed a process of fabricating tires and other articles in which the latex is used direct without first coagulating.)

The lower grades of latex and the reconditioned scraps are worked into sheets for purposes not requiring the highest quality rubber. The principal grades of plantation rubber are first-latex crêpe, first-latex

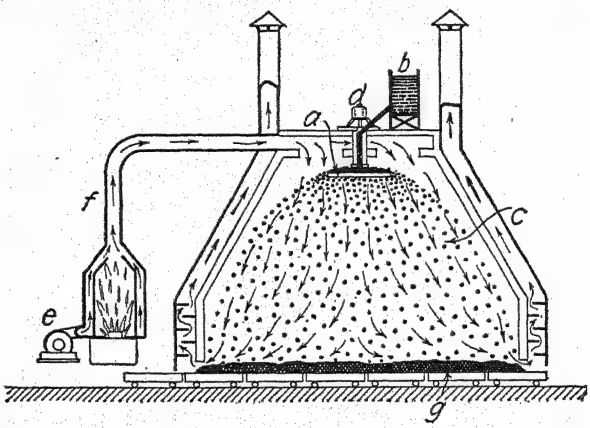

FIG. 237.—Spraying latex for rubber. *a.* Rapidly revolving disk. *b.* Tank of latex. *c.* Latex spray. *d.* Motor. *e.* Motor for producing air current. *f.* Air duct. *g.* Rubber. (*Courtesy of United States Rubber Company.*)

ribbed smoked sheet, clean brown crêpe, bark crêpe, earth crêpe, and scrap crêpe, according to the amount and character of the impurities that they contain and the quality of the latex from which they are obtained.

Up to a few years ago it was thought that rubber could be produced from the latex only by certain forms of coagulation. But recent developments have shown that this can be accomplished by converting the latex into a fine spray in a hot room and allowing

the water to evaporate. The apparatus so far developed for this purpose consists of a horizontal disk revolving at a high rate of speed. The latex is poured on to the center of the disk and is thrown off at the edge in a fine spray by centrifugal force (Fig. 237). The water and other liquids evaporate and leave the globules of pure rubber behind. It can readily be seen that if pure latex is used only pure rubber will be obtained.

Rubber Compounding[1]

In order to make crude rubber useful for the great variety of articles which are made from it today, it is necessary to mix it with a great variety of other substances. We have already learned of the importance of sulphur as an ingredient and the part it plays in vulcanization. Most rubber articles consist of about 50 per cent rubber. For the purposes for which rubber is used, the addition of certain other substances is a great improvement. When crude rubber has been mixed with other substances, the result is called a "compound." But the manner in which these substances shall be mixed in and the kinds and quantities which shall be used are matters which have required a great deal of study and experimenting. Here, for instance, are some substances used and the effect which they are supposed to produce:

Barytes.—A fairly heavy material, very powdery. Gives compound good stretch, or elasticity. Specific gravity 4.3.

Carbon-black.—Pure carbon, similar to lampblack in composition, very fine. Obtained from burning natural gas and gathering the smoke. Imparts toughness to com-

[1] Courtesy of United States Rubber Company.

pound. Makes a dry, tough, raw stock. Carbon-black compounds burn easily on mill and calender. Specific gravity 1.9.

Gilsonite.—The type of gum mined in middle-western United States. Similar in base to mineral rubber, or M. R. X. Gilsonite is used generally in footwear varnishes. Specific gravity 1.1.

Indian Red.—Oxide of iron. Dark red with purple tint. Raw material mined, large deposits in Spain, sometimes treated with heat to darken or change shade. Used as a color for dark red. Specific gravity 4.5.

Lampblack.—Pure carbon, finely powdered. Obtained by burning crude oil and collecting the smoke. Used in footwear in small quantities to give deep black compound. Differs from carbon-black in rubber in that it does not produce great strength, nor does it give a dry hard stock.

Lime Slaked.—Similar to ordinary slaked lime, except that it is more carefully prepared. Used only to speed up vulcanization of compounds.

Linseed Oil.—Oil pressed from flaxseed. Used in footwear for varnishes. Specific gravity 0.94.

Litharge.—Oxide of lead. Prepared by roasting lead with free access to air. Varies in color from orange-red to yellow. Very fine. Used in rubber compounds to speed up vulcanization. About the best common material that can be obtained for this purpose. Specific gravity 9.3.

Lithopone.—White coloring material. Consists of a mixture of barytes and sulphide of zinc. Can be obtained finely powdered. Gives a good white, but not so good as that produced by zinc oxide. Somewhat lighter in weight than zinc oxide. Specific gravity 4.2.

China Clay.—Obtained from natural deposits. White in color. Not good for coloring white compound. Can be

obtained finely powdered. Generally makes footwear compounds harsh in comparison to whiting. Specific gravity 2.58.

Red Oxide.—Oxide of iron. Similar in origin and composition to Indian red. Color varies from bright to dark red.

Resin.—Common material obtained from yellow pine, southern United States. Used as a gum in varnishes. Frequently in friction stock and cement to increase thickness. Specific gravity 1.1.

Sulphur.—Obtained by mining in Sicily or by steam hydraulic mining in southern United States. Can be obtained finely powdered, suitable for use as vulcanizer for footwear compounds. The most important chemical used in the rubber industry. Specific gravity 2.0.

Coal Tar.—By-product from coal-gas industry. Used as softener for footwear compounds. Specific gravity 1.2.

Pine Tar.—By-product of turpentine industry. Used as softener and helps vulcanization slightly.

Whiting.—Gilder's or English whiting obtained from chalk cliffs, coast of England. Finely powdered particles in round shell shape. Most popular filler for footwear compounds. Specific gravity 2.7.

Whiting.—American or limestone whiting. Sometimes used in inferior compounds, as rag, etc. Finely powdered. Particles differ in shape from English whiting. Particles are crystalline, sharp edges, not good for use in uppers, etc., causing quick aging.

Zinc Oxide.—Prepared from zinc metal by great heat with access to air. Best white coloring material for rubber compounds. Finely powdered. A good material to use but somewhat expensive and heavy. Specific gravity 5.6.

Hard Rubber (Ebonite).—Hard rubber is a product obtained by compounding raw rubber with a high percentage of sulphur—ranging from 30 to 50 per cent—together with carbon-black for coloring. Several substitutes for hard rubber have been put on the market, but nothing has yet been found to take its place for certain kinds of work. Among the common uses for hard rubber are battery boxes, pipe fittings for acid works, telephone apparatus, toilet articles, pens, and bond for high-grade artificial abrasive wheels.

Reclaimed Rubber.—Reclaimed rubber is old or waste rubber salvaged from worn-out or cast-off articles. It is never of such good quality as the new, fresh product but finds its place in insulating materials, non-wearing parts of tires, cheaper grades of mats, and other articles where special resilience and wearing qualities are not of supreme importance. It is also frequently mixed and used with new rubber in places where its presence would not be detrimental.

Methods of separating old rubber from fabrics and other foreign materials with which it is always associated are still expensive, in consequence of which reclaimed rubber is used extensively only when the high price of new rubber makes it profitable. During the recent high-price years for new rubber, reclaimed rubber furnished about 50 per cent of the whole supply of rubber used. There are two general methods of separating the old rubber from foreign materials: the mechanical and the chemical. In the mechanical method the rubber waste is ground fine,

and, after any iron has been removed with electromagnets, a blast of air carries away the bits of fabric. The product is then devulcanized by subjecting it to a high temperature and is ready to be treated in the regular manner for fabrication. In the chemical process, after the waste is ground fine, the fabric is removed by dissolving in an acid or alkali solution. From now on the treatment is the same for both processes.

Synthetic Rubber.—Synthetic rubber (rubber built up synthetically from elements) has received considerable attention in recent years. An artificial rubber known by the trade name of "Neoprene" has been developed which has attained considerable commercial importance. The substance is a product of chemical reaction from acetylene gas, a derivative of calcium carbide, which in turn is manufactured from coal, limestone, and salt. Among its special qualities are slow oxidation, resistance to acids, heat, and the deteriorating effects of greases, gasoline, kerosene, and other petroleum products. Among its most important uses are hose for gasoline pumps, gaskets and packing for oil-working machinery, printing rollers, insulation for high-tension wires, and gloves for use in chemical and paint plants.

Research is constantly being made to discover new sources of raw rubber or to produce a substitute to take its place. It is reported that Mr. Edison experimented for several years with a large number of plants in the United States in this connection and that his efforts met with considerable success. But up

to the present time little has been accomplished in the subject on a commercial scale. It is safe to assume, however, that when the real need comes, American genius and enterprise will solve the problem of our raw-rubber supply by producing the commodity from plants or other sources found within our own borders.

Rubber Terms

bark crêpe—Commercial plantation rubber of an inferior grade obtained from latex containing bits of bark or other foreign matter from the tree.

biscuit—The name applied to a mass of raw wild rubber as it comes from the coagulating process.

caoutchouc—The scientific name for raw rubber.

coagulate—The name given to thickening or hardening the rubber from the latex, either by smoking or by the use of acid.

compounding—Mixing compounding materials with rubber, as sulphur, zinc oxide, etc.

crêpe—The name given to commercial sheets of plantation rubber.

earth crêpe—Plantation rubber containing dirt obtained from latex recovered from the ground.

first-latex crêpe—The best quality of crêpe rubber.

Goodyear—An American who invented the process of vulcanizing rubber with sulphur.

gum elastic—The name given by Goodyear to vulcanized rubber.

guayule—A Mexican plant that produces rubber.

herringbone—A method of tapping a rubber tree for latex by making cuts resembling the backbone and ribs of a herring.

hevea—The name of the principal wild rubber-producing tree of the Amazon Valley, also most extensively used for plantations.

Kew Gardens—Botanical gardens in England where hevea rubber-tree seeds were first germinated for seedlings for plantations.

latex—The milky juice obtained from the rubber-tree bark, from which rubber is obtained.

lump crêpe—Plantation rubber obtained from inferior lumpy latex.

Mackintosh—A Scotchman who invented the first process of rubberizing cloth.

Para—A city at the mouth of the Amazon River from which the wild rubber of the Amazon Valley is exported.

plantation rubber—Rubber obtained from trees on a plantation.

resilience—The act or power of a substance to spring back into form after being forced out of shape.

scrap crêpe—Plantation rubber obtained from scraps and leavings of latex.

smoked ribbed crêpe—Commercial sheets of raw rubber fumigated or smoked in the curing process.

spiral tapping—Tapping a rubber tree, by cutting spiral grooves around the bark.

synthetic rubber—Rubber built up of its elements in the laboratory.

vulcanizing—Compounding and heating rubber with sulphur to give it the proper qualities.

Rubber Questions

Group I

1. What incident is related of Columbus in connection with the discovery of rubber?

2. By whom was an attempt made to produce commercial rubber in Brazil in early times?

3. In what year did the French Academy investigate rubber in the Amazon Valley? What report did they make?

4. In about what year and by whom were the first rubber articles sent to the United States?

5. What use did the early New England clipper ships make of raw rubber?

6. By whom and in what year was rubberized cloth invented? How was this accomplished?

7. Where are the principal wild-rubber regions? Where are the principal plantation-rubber sections?

8. Who gave rubber its name? Under what circumstance?

9. What was the objection to the use of rubber for coats in early times?

10. What do the following terms bring to your mind: Para; Kew Gardens; hevea; smoked crêpe; Wickham; Goodyear?

11. Name some of the earlier industries that helped the rubber industry, and state how this was brought about.

12. Name some of the first articles made of rubber. What was their main defect?

13. What is meant by the "rubber belt around the world"? Give reasons why rubber trees are found there.

14. Give the name of the man who secured rubber-tree seeds from Brazil, and tell how he secured them, where they were planted, and why they were planted in that particular place.

15. Name other countries aside from Brazil and the East Indies from which rubber is obtained.

16. Name plants in the United States from which latex can be obtained.

17. Name the common grades of plantation rubber, and explain why they are so graded.

18. Name and explain methods of coagulating latex.

19. How is hard rubber produced?

20. What is secondary rubber?

21. Name several materials used for coloring rubber, and state what color each will produce.

Group II

22. Give two reasons why the East Indies were chosen for rubber plantations.

23. Why did the Brazilian government object to having rubber seeds taken from the country?

24. How does tapping for latex differ from tapping for gum for turpentine?

25. What special qualities does rubber have that make it especially serviceable for tires; for raincoats; for insulation?

26. How are trees for rubber plantations obtained?

27. Why is plantation rubber less expensive to produce than wild rubber?

28. What modern industry has given great impetus to the rubber industry?

29. Why are raincoats sometimes called "mackintoshes"?

30. What effect may synthetic rubber have on the regular rubber industry?

31. Explain why hevea trees cannot be successfully grown in the United States.

32. Give several reasons why it is especially desirable to find sources of raw rubber in the United States.

PLASTICS

The use of plastic materials dates back to remote antiquity, when clays were first employed for the manufacture of bricks, tablets, and other articles, of which many relics are found. The modern plastic industry in this country, however, began in 1868, when John Wesley Hyatt, an American scientist, discovered that by treating cotton fiber with nitric acid, he could produce a gumlike substance that could be moulded and hardened into useful forms. To the new material he gave the name "celluloid"; so useful did it prove to be that within a few years a large industry had developed for the manufacture of celluloid billiard balls, toilet articles, novelties, and other commodities. It even went into the manufacture of collars, cuffs, shirt fronts, head bands, and bracelets. Unfortunately, however, the new material was very inflammable, and serious accidents sometimes followed its use.

The next important development in the plastic industry was the discovery, in 1890, that, by treating

the casein of common milk with formaldehyde, a product from the partial oxidation of wood alcohol, a substance resembling ivory could be obtained that was hard, durable, and beautiful and that found extensive use in the manufacture of buttons, buckles, small ornaments, novelties, and other smaller commodities.

The industry as we know it today, however, practically began in 1907, when Dr. L. H. Baekeland, a Belgian scientist, succeeded in producing a "phenolic" resin—a new material—by combining phenol (carbolic acid), a derivative from coal tar, with formaldehyde, which he named "bakelite." Since that time, especially during the past ten years, the industry has grown with leaps and bounds until articles made from plastic materials have become practically a necessity in the fabric of our everyday lives. The following paragraphs are quoted from U. S. Tariff Commission report:

The application of synthetic resins has extended into practically every branch of industry. Their uses range from jewelry and bottle closures to building materials; from adhesives and new types of surface coatings to light reflectors and shades. They are being substituted for natural materials, such as wood, metal and glass at an increasing rate. They have provided new uses for raw materials formerly used in antiseptics, disinfectants, explosives, embalming fluids, fertilizers, moth repellants and as solvents. The speed of expansion of their use in resin manufacture has been such as to create a serious shortage of these raw materials. . . .

New applications for synthetic resins appear almost daily. They are used in furniture, wall panels, builder's hardware, electrical fixtures and in thousands of other small appliances.

The automobile industry is probably the largest single user. An interesting application here is in silent gears and shaft bearings where the use of synthetic resins makes water lubrication possible. Other automotive uses of synthetic resins are in distributor heads, horn buttons, gear shift knobs, dome light reflectors, control knobs and finishing lacquers. . . . A new type of safety glass in which vinyl resins are used was introduced in 1936.

In decorative uses remarkable progress has been made. Panels of laminated resins are widely used in store fronts, lobbies of office buildings and hotels; doors faced with this material are in use. The liner "Queen Mary" is paneled, in part, with laminated resins, as is the annex to the Library of Congress. Lamp shades of urea resin are used in many Pullman cars and are available for home and office use. . . . As a result many an apparently useless by-product, such as oat hulls which yield furfural, either already are in use or being tested as a source of raw material. Other materials which have already found a place or may do are soybean meal, sugar and certain petroleum distillates.

Although it would be difficult to make a division of the subject along definite lines, all modern plastics can be roughly grouped according to the basic materials from which they are derived, as those from coal tar, those from limestone and coke, and those from animal and vegetable matter. In respect to certain characteristics they are also further divided into two groups known as "thermoplastic" and "thermosetting." The thermoplastic group consists of materials that can be moulded to desired forms under heat and pressure and that can be softened and remoulded after they have become hardened. This has the

advantage of permitting scrap and discarded articles of being salvaged and worked over again into useful forms. Thermosetting materials, although capable of being formed under heat and pressure, when once hardened, cannot again be softened and remoulded and are not affected by ordinary acids or solvents. In other words, they cannot be reformed by heating

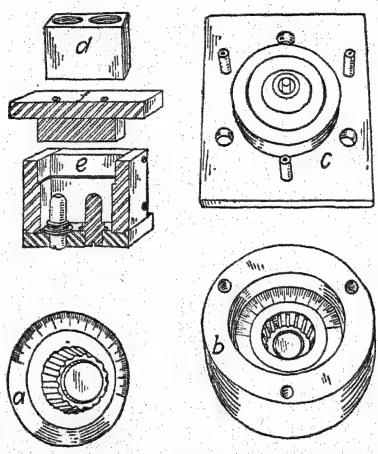

Fig. 238.—Bakelite moulds. *a.* Radio dial. *b.* Bottom part of mould. *c.* Top part of mould. *d.* Fixture. *e.* Bottom part of mould. *f.* Top part of mould. (*Courtesy of Bakelite Corporation.*)

when once they have become set. Unlike thermoplastic materials, which cool in the moulds, they can be removed in a few minutes at high temperature in a solid, permanent state. Plastics can again be classified according to the processes by which they are formed into commercial products, as moulded, extruded, cast, laminated, and cements (Figs. 238, 238*a*). The materials are also used extensively in liquid form, for varnish, enamels, lacquers, and other protective

coatings. Except with those used as liquids, fillers are generally required to be mixed with the resins to give them body and other desirable qualities. Among the more common fillers being used are wood flour, soybean meal, masticated canvas, asbestos fiber, ground mica, and paper.

It would occupy too much space and time to enumerate even the trade names of all the different brands of plastics in use. Mention of some of the more common kinds will be sufficient. With few exceptions companies that make plastic resins do not fabricate their products into finished articles of commerce but sell the raw materials to concerns that specialize in turning out various lines of commodities, much after the practice of lumbermen who sell their rough ware to builders, furniture producers, and other manufacturers of wood products. General standard, stock plastic materials are powders, in granulated form, sheets, rods, and tubes. Almost any form desired, however, can be had on order. Moulded articles are produced in strong steel dies or moulds under pressure of from 1,000 to 3,000 pounds per square inch at a temperature of about 350°F. The materials are prepared by thoroughly mixing the resinoid with the filler and adding coloring matter, if colors are desired, and then pressing the mixture firmly into strong, heated moulds. (Coloring materials are usually dyes or pigments.) Wood-flour moulded articles are commonly used where non-conductive qualities are needed and for commodities requiring strength, sharp corners, and superior finish.

Among these are radio parts, automobile distributor heads and other automobile accessories, switch plates, doorknobs, pen and pencil barrels, tube caps, bottle covers, and toilet articles. Asbestos-fiber mixtures are prepared for moulding practically in the same manner as those for wood-fiber mixtures. They resist higher temperatures better and are generally more

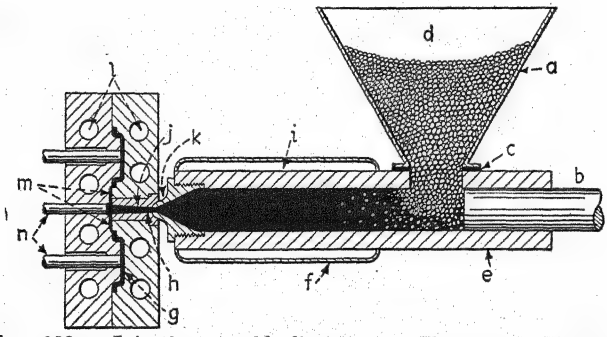

FIG. 238*a*.—Injection mould diagram. *a*. Hopper. *b*. Plunger. *c*. Insulation. *d*. Prepared plastic material. *e*. Cylinder. *f*. Jacket. *g*. Plastic casting. *h*. Orifice. *i*. Heating space. *j*. Gate. *k*. Nozzle. *l*. Cooling channels. *m*. Runners. *n*. Knockout pins. (*Courtesy of Tennessee Eastman Corporation.*)

suitable for out-of-door service and where resistance to water, oils, and acids is of prime importance. Soybean meal is used for plastics largely for automobile accessories and other general work. Canvas is employed where special strength is required and ground mica, for insulation ware. For thin, flat pieces of uniform cross-section, such as gear blanks, pulleys, washers, disks, and other flatwork, layers of paper, preferably of linen or canvas, impregnated with resinoid, are built up and pressed between hot plates under hydraulic pressure. Gear teeth require final

shaping by machine, as also do other details of form that cannot be secured by moulding.

A superior grade of varnish has been developed by the use of phenolic resin. It is produced by dissolving the resin in a solvent and is used extensively as an insulating bond and protective coating for coils, armatures, and windings. It is also used for finish and protective coatings for wood, clay, and metal products. In some instances, after being applied, it is hardened and improved by baking, although in recent years excellent varnishes have been developed that do not require the baking process.

There are many commercial forms of plastic materials on the market. A brief description of a few typical forms will suffice at this time.

Phenolic-resin Group.—Bakelite is among the most outstanding of the plastic resin group. (The term "bakelite" is also used to represent a series of substances, including urea, cellulose, polystyrene, and other plastics.) Bakelite phenolic resin is obtained by the combination and chemical reaction of phenol (carbolic acid) and formaldehyde. The two materials are weighed out carefully and thoroughly mixed and then subjected to heat in a steam-jacketed kettle for several hours. Chemical reaction takes place, and the contents of the kettle are found to be water on the top and a molten layer of resinoid on the bottom. In its primary state the resinoid can be melted and will dissolve in alcohol or acetone, but, once processed, it is infusible, insoluble, hard, strong, and permanent. Another important phenolic resin product, with the

trade name Durite, is a furfural-phenol compound. Furfural is obtained from oat hulls, corncobs, rice hulls, peanut shells and other farm waste. It not only acts as an aldehyde to combine with phenolic resin to produce a valuable plastic but can be reduced to a synthetic resin in its own right. It also acts as a solvent, plasticizer, hardening agent, and resin-forming reagent all in one. Furfural and its derivatives added to road-building materials provide a bond of remarkable strength and water resistance. As phenol-furfural resin it can be used in practically all forms of plastic products. Other phenolic resin compounds are known as Marblette, Durez, Lamicoid, and a long list of others, each generally produced by a different company and each having special qualities suited to various purposes.

Marblette is a pure synthetic resin containing no fillers and must not be confused with casein, molding powders or cellulose products. The fluid resin is poured by hand into open lead molds and then subjected to baking which converts the liquid into a tough solid which is non-inflammable, insoluble, infusible and which can be readily turned, sawed, sanded, drilled, threaded, carved and embossed. A high lasting polish is produced by means of a buffing wheel and rouge or by the tumbling barrel method. Marblette, produced in all colors, is sold in sheets, rods, tubes and special shapes in opaque, translucent and transparent form in either plain or mottled effects. Marblette "Crystle" is a transparent, waterclear cast phenolic resin.

Vinyl Resins.—Vinylite resins are obtained from acetylene, which, in turn, comes from limestone and

coke. There are several types of the commodity on the market, among the most important of which is vinyl plastic, which finds extensive use as the inner layer in laminated window glass for automobiles, streetcars, railroad cars, etc. The plastic can be rolled into sheets no thicker than heavy paper, which, when placed between panels of glass and subjected to heat and pressure, becomes transparent and binds the glass together into one solid, clear piece. It is used extensively for multiple-plate, or bulletproof glass, also for transparent paper, as a component for paint, varnish, and lacquer, for moulded articles, and in chewing gum. Among other vinyl-resin products, we find the trade names Butacite, Alvar, and Butvar.

Cellulose Acetate.—Tenite is typical of this group of plastics. It is thermoplastic in nature and is characterized by special toughness and resilience in consequence of which it is adapted to thin-walled, moulded articles where a more brittle material would not stand up. It is produced in a large variety of colors and combinations and because of its low conductivity of heat and its smoothness to the touch is especially adapted for toilet articles, pens, pencils, handles, spectacle frames, electrical appliances, and many other commodities that come in contact with the skin. It is also extensively used in photographic films. Other trade names for cellulose-acetate materials are Lumarith, Nixonite, Plasticele, and Monsento, C.A.

Cellulose Nitrate.—Cellulose-nitrate plastics are used to some extent, although relatively less than in

former years. Pyralin is typical of this group. It is produced by treating cotton linters with nitric acid to form pyroxylin, to which are added camphor, alcohol, and color for a celluloid, which, in turn, is rolled, baked, seasoned, and polished and is ready for use. Pyralin, like many other plastics, can be made in practically every shade and color desired and from transparent and translucent through mottled and variegated effects to opaque. Trade names for other cellulose-nitrate products are celluloid, Nixonoid, and Monsanto C.N. Cellulose-nitrate plastics are especially susceptible to coloring materials, in consequence of which very beautiful shades and hues can be obtained.

Urea-formaldehyde.—Urea-formaldehyde resins are produced indirectly from four gases, ammonia, carbon dioxide, hydrogen, and carbon monoxide. Ammonia and carbon dioxide react to form urea, and hydrogen and carbon monoxide, to yield methyl alcohol, which, in turn, is converted into formaldehyde. Plaskon is typical of plastics from this source. It is outstanding largely because of its brilliancy and color possibilities. Uncolored urea resin is highly translucent and gives high light transmission and diffusion. For this reason it finds extensive use for shades and reflectors for both direct- and indirect-lighting fixtures. Other uses of the resins are for surface coatings and adhesives. Trade names of other urea-formaldehyde plastics are Beetle and Plasicon. Among other plastics is Polystyrene, a product obtained from a combination of ethylene,

from petroleum or natural gas, and benzene, from the by-product coke oven. It is a clear, colorless, thermoplastic material, highly insulating, strong, and moistureproof. It is especially adapted for transparent, translucent, and opaque articles in a wide variety of colors. It is also used in lacquers and light-colored enamels. Another resin is Acrylate, produced from acrylic acid from fats. It is colorless (transparent) thermoplastic, has great elasticity and chemical resistance. It can be had in a liquid or solid state and is used extensively in laminated glass, moulded articles, and coatings. It is marketed under the trade names of Crystalite, Lucite, and Pexiglas. Shellac and hard rubber are also important plastics. Hard rubber comes out under the names Rub-tex, Luzerne, Neoprene, and Amerite. Masonite is also classified as a plastic (lignin plastic) under the trade names Beneloid and Benalite.

Research work in the field of plastics is constantly going on, and the number and variety of new material discovered is increasing daily. One large producer reports that over two thousand different plastic substances have been developed in its laboratories.

Masonite.—Although Masonite, as such, might not always be classified as a plastic, that is definitely one of its forms, and the classification will serve our purpose for identification in this connection.

Masonite is a comparatively new construction material produced from wood fiber. There are several grades of the commodity on the market, each having qualities suited for particular purposes.

The Masonite industry started with the idea of utilizing mill waste for its raw material, of which there were enormous quantities connected with our Southern saw mills and which had to be burned to be got rid of. But the industry soon grew to such proportions that this source of supply was no longer adequate, and wood directly from the forests had to supplement it. It is the policy of the producers, however, to use only wood that is not suitable for other purposes.

In the process, the wood is chipped into pieces about ¾ inch long and confined in a strong steel container, or "gun." Steam pressure of about 600 pounds per square inch is applied and then suddenly raised to 1,000 or 1,200 pounds and held for about 2 seconds, after which the gun is discharged through a valve in the bottom into a "cyclone," where the steam and fiber are separated. The sudden releasing of the great pressure on the chips causes them to explode and separate into fibers without destroying the lignin with which they are associated. Less than a minute is required from the time the chips are charged into the gun until they are discharged as fiber.

After being refined, the fiber is formed and pressed into sheets in like manner as paper. It is spread out on screens in mats of the required thickness and subjected to heat and to a pressure of from 210 to 1,200 pounds per square inch in a powerful hydraulic press from which it comes out perfectly dry and in solid sheet form. The common standard size of these sheets is 4 by 12 feet, but they can be had in a variety of other sizes.

At the present time Masonite finds use in building construction for walls, floors, ceilings, wainscoting, cabinetwork, panels, and other purposes; and in recent years it has found an increasing market for coverings and other parts of house trailers. The more porous grades are used for insulation and in places where size and decorations are to be applied. For bathrooms and kitchens, scored sheets after the manner of square wall tile are furnished, and for floors and other places where strength and wearing qualities are of special importance, the board is made very hard and strong.

A careful analysis discloses that wood is composed of minute fibers—cellulose—held together by a substance known as "lignin." It was assumed that if these two materials could be separated from the foreign matter and again cemented together under proper conditions a wood substance could be produced embodying certain qualities superior to those of the original wood itself. That the theory was correct has been proved. Not only has the industry furnished us with a new medium of construction of exceptional beauty and efficiency, but also it is utilizing waste and the less important parts of our wood supply and thus saving the more important parts for other valuable and necessary uses.

Plastics Terms

casein—The curd matter of milk.

filler—Any substance combined with a plastic resin to give it body, strength, or other special qualities.

formaldehyde—A product obtained from the partial oxidation of wood alcohol.

furfural—A substance obtained from oat hulls, corncobs, rice hulls, and other farm waste.

laminated plastics—Sheets of plastic materials produced by impregnating layers of paper, canvas, or other fabrics with resin and subjecting then to high pressure between hot plates.

multiple-plate glass—Sheets of glass built up of layers of glass and layers of plastic material and cemented together.

phenol (carbolic acid)—A product obtained from the distillate of bituminous coal.

plasticizer—Any substance that renders another substance plastic when combined with it.

resinoid—A resinlike or synthetic resin substance.

synthetic resin—Artificial resin produced by chemical reaction.

thermoplastic—Any material that becomes soft or plastic by the application of heat.

thermosetting—Any material that becomes set or hard by the application of heat—and generally pressure—and that cannot be softened again or made plastic by reapplication of heat.

wood flour—Wood ground to fine or powderlike particles.

sprue—The opening or short channel through which plastic materials flow to the gate to the mould in moulding plastic articles, or the waste material left in the channel after the mould is filled.

Plastic Questions

Group I

1. Name the raw materials used in the production of phenolic resin.
2. Name five general divisions of plastic-producing materials.
3. From what are carbolic acid and formaldehyde obtained?
4. What are the raw materials for celluloid?
5. By whom and in what year was celluloid discovered?
6. How is bakelite phenolic resin produced?

7. Of what materials are motion-picture films generally made?

8. Name the essential difference between thermoplastic and thermosetting plastics.

9. What two important structures are mentioned in the text as having panels of plastics in their interior finish?

10. How are colors produced in plastics?

11. What materials are generally used for coloring plastics?

12. How many pounds pressure and what temperature are generally required in producing laminated or moulded plastic articles?

13. What is meant by "synthetic" resin?

14. Name some of the materials for which plastics can be substituted and also articles in which they are used.

15. What is meant by a filler? Name materials used for fillers.

16. What is meant by injection moulding?

17. How does injection moulding differ from compression moulding?

18. Name the materials used in the production of Masonite

GROUP II

19. What is the main objection to using nitrocellulose for motion-picture films?

20. Why are plastic-coated articles sometimes baked after being coated?

21. Explain why the color on plastic material seldom rubs off.

22. How are varicolored plastics produced?

23. Explain why plywood made with plastic resin is good for out-of-door work. Why is it especially good for boat building?

24. Give two reasons why phenolic resin is good for producing plywood.

25. Give three reasons why plastics are especially adapted for electrical work.

26. Give reasons why plastic trim buttons, etc., for automobiles are better than metal.

27. Give several reasons why plastics are especially good for toilet articles.

28. What would seem to limit the size of articles made of plastics?

29. Why are plastic gears desirable in some places?

30. Explain the difference between laminated, cast, moulded, extruded, and injected plastics.

31. A steel handle always feels colder to the touch than a plastic handle at atmospheric temperature. Why?

32. Give three reasons why plastics make good automobile steering wheels.

33. Name three special qualities that plastic material must have for automobile window glass.

34. Explain what is meant by "compression" moulding.

35. Name a special advantage of thermoplastics over thermosetting materials, and vice versa.

36. Why would you say the trade name Marblette is given to a certain brand of plastic articles?

37. Where does the name bakelite come from?

PAINT, STAINS, AND VARNISHES

Paint.—Generally speaking, paint can be defined as a liquid composed of (1) a pigment, *i.e.*, a very fine powder; (2) an oil called a "vehicle"; (3) a thinner; and (4) a drier.

There are many kinds and colors of pigments in use for paints, depending upon the nature of the raw materials from which they are obtained and the process employed in their production. Among the more common of these are white lead, titanium, natural and processed earths, carbon, lithopone, zinc, and other metallic oxides.

White Lead.—White lead is one of the most important and useful of the pigments. It can be manufactured by a number of processes, among which are the Dutch, the Carter, the Mild, and the electrolytic

processes. A brief description of these processes will be sufficient for our purpose at the present time.

In the Dutch process pure metallic lead is cast into disks, or "buckles," about 6 inches in diameter (Fig.

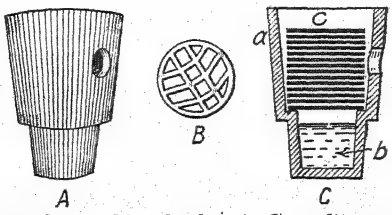

FIG. 239.—Corroding white lead. *A*. Corroding pot. *B*. Metallic lead buckle. *C*. Cross-section of filled pot. *a*. Pot. *b*. Acetic acid. *c*. Stacks of metallic lead buckles. (*Courtesy of National Lead Company.*)

239*B*). A number of these buckles are placed flat in a corroding pot, consisting of a clay container, resem-

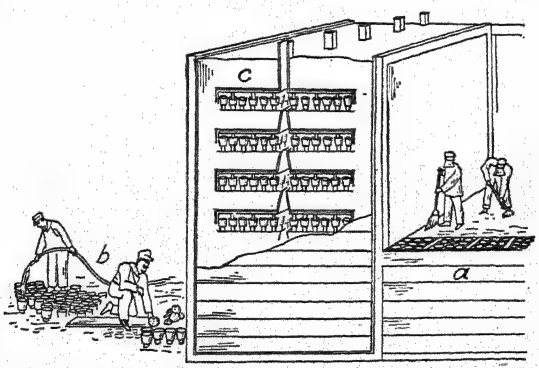

FIG. 240.—Corroding white lead. *a*. Stripping stack. *b*. Filling pots with acetic acid and lead buckles. *c*. Stack of pots complete. (*Courtesy of National Lead Company.*)

bling a flowerpot, about 10 inches high by 7 inches in diameter at the top and 4 inches in diameter at the bottom and having a ledge about one-third the distance up for supporting the buckles (Fig. 239*A*). Holes are constructed in the sides of the pot to allow for the free

circulation of gases. Dilute acetic acid is placed in the bottom section, and the buckles are piled in on the ledge (Fig. 239*C*). The pots are then placed in alternate layers, or tiers, in a stack house, closely packed in spent tanbark until the room is full (Fig. 240). They are allowed to remain in this condition for from 100 to 150 days, during which time the tanbark ferments and the temperature rises to about

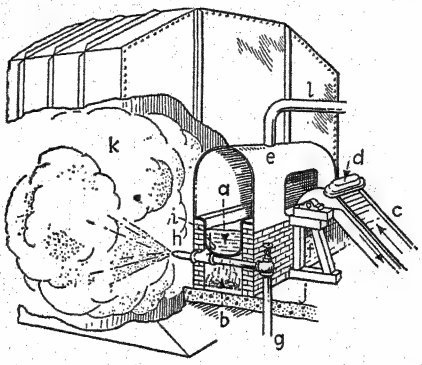

FIG. 241.—White lead production, Carter process. *a*. Molten metallic lead. *b*. Furnace. *c*. Belt conveyor. *d*. Pig lead. *e*. Hood. *f*. Supports. *g*. Air pipe. *h*. Spray nozzle. *i*. Molten lead intake. *j*. Concrete floor. *k*. Collecting chamber. *l*. Vent pipe. (*Courtesy of J. A. Zang, Sales Manager National Lead Co., Atlantic Branch.*)

185°F., generating carbon dioxide and causing the acetic acid to vaporize. The vapor fumes attack the metallic lead and convert it into lead acetate, and the carbon dioxide in turn converts the lead acetate into basic carbonate of lead, or the white lead of paint. The white lead is next ground very fine, screened and cleaned, and is ready to be mixed with a vehicle and become a paint.

In the Carter process, molten metallic lead is atomized by compressed air in similar manner to the

action of a nasal atomizer (Fig. 241), which leaves the metal in very fine particles or powdered form. It is then charged into wooden cylinders that revolve very slowly on horizontal axes, keeping the lead con-

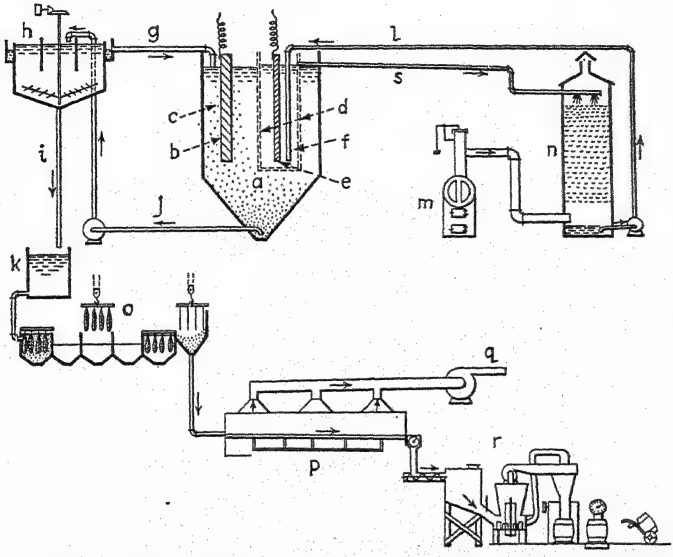

FIG. 242.—Sperry electric white lead process. *a*. Cell tank. *b*. Metallic lead anode. *c*. Anolyte. *d*. Fabric partition. *e*. Iron cathode. *f*. Catholyte. *g*. Anolyte pipe. *h*. Thickener. *i*. Settled white lead. *j*. Solution containing lead carbonate or white lead. *k*. Pulp lead storage. *l*. Carbonated catholyte. *m*. Steam generator. *n*. Carbonating tower. *o*. Vacuum filter. *p*. Dryer. *q*. Vapor exhaust fan. *r*. Pulverizing and air floating apparatus. *s*. Spent catholyte. (*Courtesy of Anaconda Lead Products Co.*)

stantly in motion and bringing all parts into contact with the corroding agents. Dilute acetic acid and carbon dioxide (carbonic acid) are added, causing the metallic lead to corrode and form lead carbonate or white lead. The action of the acetic acid on the metallic lead produces lead acetate, which, in turn, is acted upon by the carbon dioxide to produce white

lead. Chemically the process of the production of white lead by the Carter process is the same as that of the Dutch process.

The apparatus for the manufacture of white lead by electricity is somewhat similar to that for refining copper (Fig. 227). It consists, in the main, of a concrete electric cell in which are suspended metallic lead anodes and insoluble iron cathodes. The cathodes are enclosed in the cell in porous fabric envelopes that keep them separated from the anodes. In these fabric envelopes is an electrolytic solution (the catholyte) composed of sodium acetate and a large amount of sodium carbonate. The tank proper is filled with an electrolytic solution (the anolyte), containing sodium acetate and a small amount of sodium carbonate, in which the anodes are submerged. Each electrolyte is maintained in rapid circulation independently from the other by a direct current. Some of the catholyte under the influence of the current seeps through the fabric envelope to the anolyte and acts to precipitate lead carbonate from the metallic lead dissolved from the anodes. The continuous flow of the anolyte removes the white lead as fast as it is formed, and, after being settled and washed to remove the anolyte solution, it is dried, ground, and air-floated and is ready for use.

Titanium.—Titanium oxide is among the most important of the white pigments. Paints made from it have exceptionally stable qualities, retain their

color under very severe conditions, are durable, and have much greater opacity and covering power than white lead. The pigment is made by chemical means from the mineral ilmenite, a compound of iron oxide and titanium dioxide, vast deposits of which are found on the west coast of Norway, in India, the United States, and elsewhere.

Earth Pigments.—There are many varieties and colors of earth pigments, natural, calcined, or otherwise processed to produce certain qualities and colors. Iron oxides form a very important group of these. They are widely distributed and vary considerably as to both shade and purity. The following are a few of the more common varieties of earth pigments:

Indian red, Venetian red, black lead, yellow ochre, sienna, umber, Vandyke brown, and metallic, or mineral, brown.

Indian red was formerly obtained as a natural earth, but in recent years it is produced largely by chemical process. It gives a deep purplish red.

Venetian red was also formerly a natural earth, containing a high percentage of iron oxide, but it is now produced by artificial means. It makes a cheap, durable paint and is used largely for rougher work, as barns, warehouses, etc.

Black lead is a natural graphite, a form of carbon found in many parts of the world. It is a grayish black and is used largely for protecting ironwork and other metal surfaces.

Yellow ochre is a natural earth and is found in many parts of the world, the best grades coming from France. Formerly it was used largely for priming coats on wood but is not so used at the present time in the best painting practice. It is used by itself or mixed with other pigments to make color.

Sienna is a natural earth of brownish-yellow color when raw. When burned it gives an orange-red color of rich tone. It is used largely for coloring and tinting and making stains.

Umber is a natural earth of a yellowish-brown color. It is found in many parts of the world, the best grade coming from the island of Cyprus. When burned, it is known as "burnt" umber and is of a dark-brown color. It is used largely in stains, for making colors and tinting.

Vandyke brown is a natural earth found in or near bogs and contains considerable organic matter. It is used largely for coloring and tinting. Ground in oil it makes a good walnut stain.

Metallic or mineral browns are obtained from a variety of native ores mined more especially in the Appalachian region. As a rule, the ores are roasted and develop colors ranging from bright red to dark purple. They are used for general rougher painting.

Aside from the large number of natural earth pigments there is a large variety produced by chemical reactions. The following are a few of the more important ones: Prussian blue, ultramarine blue, cobalt blue, chromes, blacks, zinc oxide, and lithopone.

Prussian blue is a strong, deep blue used largely for tinting and coloring, also as a dipping paint. It is produced by chemical means.

Ultramarine blue was formerly obtained from a semiprecious stone but is now produced artificially. It is used largely in house painting, for tinting and coloring, and on fancy articles.

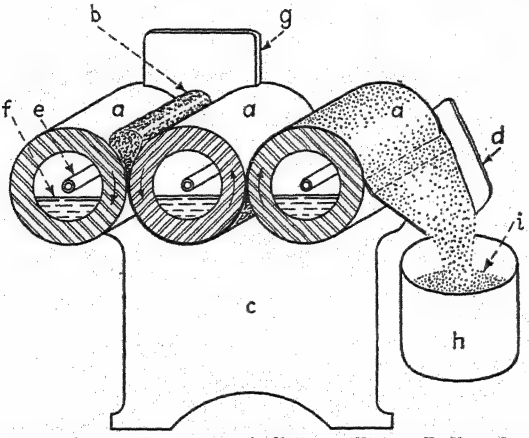

FIG. 243.—Three-roll paint-grinding mill. *a.* Rolls. *b.* Materials before grinding. *c.* Frame. *d.* Apron. *e.* Pipe for cooling. *f.* Water for cooling. *g.* Color blade or end regulator. *h.* Paint container. *i.* Paint. (*Courtesy of Charles Ross and Son Co.*)

Cobalt blue is produced from aluminum and cobalt oxides by chemical reactions. It gives a greenish-blue color. Because of its high cost its use is limited.

The chromes comprise principally chrome yellow, chrome green, and chrome red, or American vermilion. Chrome yellow is a compound of lead with chromic acid and ranges in color from a deep orange to a light yellow. Chrome green can be produced by mixing together Prussian blue and chrome yellow. It is also

produced chemically. Chrome red, or American vermilion, is a basic chromate of lead.

Among the more common black pigments are lampblack, gas black, boneblack, and charcoal black. Lampblack is produced by the incomplete combustion of oils, fats, resins, etc. It is nearly pure carbon, is of a grayish black, and is used largely for coloring or shading other paints. Gas black is produced from the imperfect combustion of natural gas. Its nature and uses are similar to those of lampblack, but it gives a deeper and more permanent black. It is also used extensively for black enamels. Boneblack is produced by burning bones in the absence of air, especially sheep bones. It is a high-grade black pigment and is used largely for carriage and other high-grade paints and enamels. It is also called "coach black." Ivory black, sometimes called "drop black," is a high-grade boneblack. The best grades are produced from burned or charred ivory chips, but owing to the scarcity of ivory in recent years, so-called "ivory black" is produced largely from bones. Ground in oil, ivory black makes a permanent high-grade black paint or enamel. It is used largely for coloring and tinting. Charcoal black is produced by grinding charcoal. The best charcoal for the purpose is obtained from peach and plum pits, cocoanut shells, cork waste, and grape-vine cuttings.

Zinc oxide is a very fine white pigment. It is produced, in the main, by vaporizing metallic zinc and collecting the zinc oxide from the vapors in long chambers. It is also produced by heating ores con-

taining zinc with coal. It is used in the best grades of white enamels and in flat interior paints and is also mixed with other pigments to improve the quality of these paints.

Lithopone is a very fine white pigment. It is produced by chemical means and is composed of barium sulphate and zinc sulphide. It is used largely for flat paint for interior work and to a certain extent for enamels.

Extenders.—In addition to the regular pigments there are other materials or pigments used in paints known as "extenders." They are used largely as adulterants or to increase the volume, although it is claimed that in some instances they extend the life of the paint. The more common extenders are whiting, chalk, gypsum, silica, and marble dust.

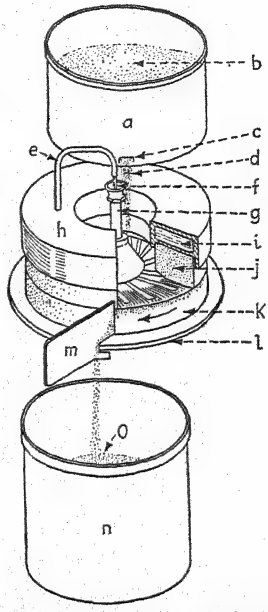

FIG. 244.—Stone paint-grinding mill. *a.* Feeder pot. *b.* Material before grinding. *c.* Gate. *d.* Material passing from feeder. *e.* Goose-neck water pipe. *f.* Water. *g.* Runner-stone water pipe. *h.* Stationary stone housing. *i.* Water for cooling. *j.* Stationary stone. *k.* Runner stone. *l.* Runner-stone housing. *m.* Scraper for take-off. *n.* Paint container. *o.* Finished material or paint. (*Courtesy of Charles Ross and Son Co.*)

Enamels are very fine-quality paints. They are produced by grinding high-grade pigments in varnish instead of oil. The best French enamels are made from zinc oxide. When colors are desired, they are produced by adding a suitable coloring material.

Bronzes.—The bronzes are very finely divided metals or metal alloys mixed with some liquid that will dry to a hard, tough, thin film. They are designated by the name of the metal entering into their composition or by their color, as "aluminum bronze," "copper bronze," and "gold bronze." Gold bronze is produced from an alloy of copper, zinc, and tin. Bronzes are used largely for decorating radiators, pipes, and other metal articles where their heat-resisting qualities are of special value. They also find use in the arts and for protection.

Linseed Oil.—Linseed oil is one of the most important of the paint vehicles. It is produced from flaxseed and is extracted by first crushing the seeds and afterward subjecting the meal to high pressure at a temperature that will allow the oil to flow freely (about 160°F.). The residue or cake left is used in European countries for cattle feed. The oil is refined and comes on to the market as raw oil and boiled oil. Raw oil is the product as it comes from the initial refining process. It is transparent and of a light amber color. As a rule, it is too slow drying to be used alone. Boiled oil is obtained by heating the raw oil with lead or manganese oxide, some of the metal going into solution and causing the oil to dry more readily. Linseed oil dries with a tough, rubber-like film, which makes it especially valuable as a paint oil. In certain Eastern countries cold pressed linseed oil is used for food.

Tung Oil, or China-wood Oil.—Tung oil is obtained from the seeds of the China-wood tree found mostly

in China. It is extracted from the seeds in much the same way as linseed oil. It is used largely in flat paints and in waterproof varnishes and is mixed with other oils for ordinary paints and varnishes. Experiments are being made growing China-wood trees in our Southern states; in fact, several large tung-tree orchards are being successfully operated in Florida and other states.

Menhaden Oil.—Menhaden oil is a fish oil and is obtained from the menhaden fish by boiling, the residue being used for fertilizer. The oil is not so good for paint as linseed oil but is sometimes mixed with the latter. It is used to a considerable extent in the manufacture of linoleums.

Soya-bean Oil.—Soya-bean oil is a product obtained from the soya bean grown largely in Manchuria and Korea. As a rule, soya-bean oil is mixed with linseed oil, as it does not dry well when used alone.

Thinners.—Thinners are liquids mixed with paint to make it more liquid so that it will flow more easily. Turpentine is the most important of the volatile thinners. Substitutes for turpentine are petroleum distillates, especially those with an asphaltic base, and are known in trade as white spirits, benzene, and mineral turpentine. Coal-tar naphtha, a distillate of light oil from coal tar, is also used as a thinner, especially for bituminous paints and varnishes. Other thinners, as denatured and wood alcohols, are used largely for shellac varnish. The particular thinner to be selected depends upon the nature of the paint or varnish and the use to which it is to be put.

Driers.—"Driers are metallic salts capable of promoting an accelerated rate of drying in an oil or oleoresinous film." They are commonly known as "oil" or "Japan" driers and are produced by cooking the oxides of lead manganese or cobalt in oil and rosin and then thinning with a suitable solvent, as turpentine or petroleum spirits. They are also produced chemically from naphthenic acid and metals, the principal metals used being cobalt, manganese, and lead. They not only accelerate the drying process but also assist in giving the paint a hard, durable film.

Lakes.—Lakes are colors formed by combining the coloring matter of certain coal-tar dyes with metallic bases. They are used in the paint and varnish industry largely in stains or mixed with paints to produce body and special color effect. They can be obtained in a large variety of colors.

Asphaltum.—Asphaltum paints and varnishes are produced from asphaltic pitch, the two principal varieties being manjak and gilsonite. The commodities are made by dissolving the pitch in some form of petroleum or coal-tar solvent. Asphaltum paints and varnishes are used more especially as a coating for iron or other metalwork for protection.

Water Paint.—Water paint enters into the composition of paints only to a limited extent. The more common ones are whitewash, Portland cement wash, and calcimine. Whitewash is one of its most common forms. It is produced by mixing slaked lime with water and sometimes adding skimmed milk, glue, alum, soap, or other material as a binder. Besides

its covering and coloring qualities, whitewash is especially valuable as a sanitary coating. Washes or paints made by mixing water with Portland cement are also serviceable, especially in places exposed to dampness. Calcimine is a cold-water paint produced by mixing whiting with cold water and adding a certain amount of glue. Any tint desired can be secured by adding coloring matter that can be dissolved in the water. Calcimine is used almost exclusively for interior decorations. In addition to the older water coatings, great strides have been made in the manufacture and use of casein paints that are water soluble for application.

Stains.—Stains are liquids applied to wood surfaces to change or modify the color and to bring out certain grain effects. There are three general classes of stains on the market: oil stains, spirit stains, and water stains. Oil stains are produced by mixing high-grade pigments with the proper kind and amount of oil and adding thinner, as turpentine, benzene, or naphtha solvent, until the desired quality is secured. For certain grades of work, stains are sometimes made by simply mixing the pigments with solvents without oil.

The following are formulae for some of the more common stains:

Light oak.....	50 per cent raw sienna, 50 per cent yellow ochre
Dark oak.....	80 per cent raw sienna, 10 per cent each burnt sienna and burnt umber
Walnut.....	50 per cent Vandyke brown, 50 per cent burnt umber
Mahogany.....	60 per cent burnt sienna, 40 per cent maroon lake

Spirit stains are generally solutions of wood or denatured alcohol and certain kinds of dyes. They are clear, penetrate deeply into the wood, and do not obscure the grain as oil stains are sometimes apt to do. They raise the grain of the wood, however, and leave a rough surface which must be smoothed afterward if the best finishes are to be obtained.

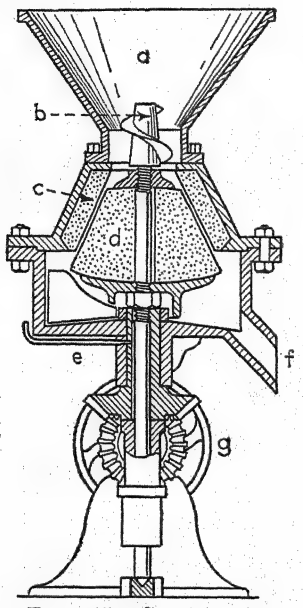

Fig. 245.—Conical Buhr stone mill for paint. *a.* Hopper. *b.* Spiral feed worm. *c.* Stationary pot. *d.* Runner stone. *e.* Oil pipe. *f.* Spout. *g.* Bevel gear. (*Courtesy of Charles Ross and Son Co.*)

Water stains are largely aniline (coal-tar) dyes. They can be made in a large variety of colors, but their tendency is to fade when exposed to the light. Vinegar added to certain varieties of water stains sometimes retards fading.

Varnishes.—Varnishes may be defined as any liquids, not containing pigments, used for decoration or protection and capable of being spread in a thin, homogeneous film that will dry to a hard coating. They may be classified as oil varnishes and spirit varnishes.

Oil varnishes are those produced by combining certain kinds of gums or resins with linseed, tung, or some other oil and the proper amount of thinner and drier. In the process of production the gums and oils are

heated separately and then mixed together. The mixture is then heated and stirred until the proper consistency is reached, after which the varnish is cooled and the proper amount of drier and thinner is added. Some of the best grades are stored for several months before being ready for use. The aging process allows the varnish to settle thoroughly and also to absorb oxygen, which increases its drying qualities.

Oil varnishes are also classified as "long oil" or "short oil," according to the percentage of oil used in their production. They are also designated according to their nature and uses, such as inside varnish, spar varnish, floor varnish, furniture varnish, rubbing varnish, insulating varnish, and others.

The best gums used for oil varnishes are the copal-fossil gums designated as Zanzibar, Kauri, Manila, Congo copal, and others. Colophony, or pine-tree rosin, is also used to a considerable extent, either alone or mixed with other gums. As a rule, however, varnishes made from ordinary pine rosin are not of so good quality as those made from fossil gums. The supply of fossil gums is beginning to become exhausted, in consequence of which substitutes are constantly being sought to take their place.

Spirit varnishes are made by dissolving some sort of gum or rosin in a solvent, as wood or denatured alcohol, turpentine, acetone, or some of the mineral spirits. Among the more common spirit varnishes are dammar and shellac. Dammar is a product from a tree in the East Indies and is generally classified as Singapore dammar, Batavia dammar, etc., according

to the locality from which it is obtained. Dammar varnish is produced by melting dammar in turpentine or in white spirits. It is used largely as a coating for paper and is sometimes known as "crystal paper varnish." It is also used to a considerable extent in enamels.

Shellac varnish is produced by dissolving gum shellac in wood or denatured alcohol. The gum comes

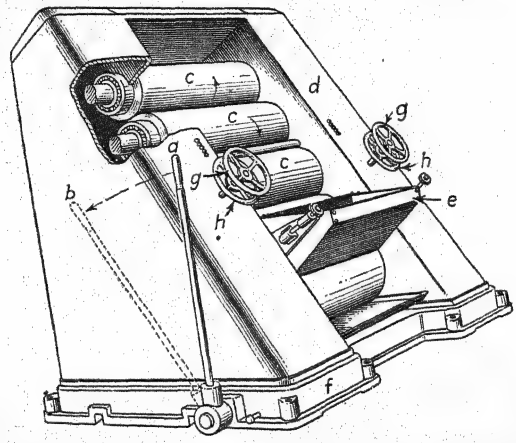

FIG. 246.—Kent super five-roller paint mill. *a*, *b*. Roll adjusting lever. *c*. Rolls. *d*. Frame. *e*. Hopper. *f*. Base. *g*, *h*. Hand wheel for setting rolls. (*Courtesy of Kent Machine Works Inc.*)

principally from India. It is a hard secretion of a very small insect, known as the "lac insect," which attaches itself to the branches of several kinds of trees. There are several shades and grades of shellac, but in general it is classified into two main divisions: orange shellac and white shellac. Orange shellac is the natural product and is obtained directly from the secretion and needs no other treatment than cleaning and refining to make it ready for use. Its natural

color is orange, hence the name. White shellac is produced by bleaching orange shellac. This is accomplished by dissolving orange shellac in a water solution of borax or soda, treating it with chlorine gas or some other bleaching solution, and then drying. Colored shellacs are made by adding coloring matter such as concentrated aniline dyes, lampblack, ivory black, and quicksilver vermilion. Shellac has a wide variety of uses not only as a varnish but also in cements, fillers, as a plastic, and for other special purposes in the industries. Because of its moisture-resisting qualities it is especially serviceable for a coating for surfaces exposed to dampness. For this reason it is used extensively for coating wooden patterns for castings in foundry practice.

Lacquers are becoming of more and more importance, especially in automobile construction as a body finish, because of their durability, protective qualities, and artistic effects. Any thin spirit varnish containing shellac or other resins may be considered a lacquer. But in recent years the best products are made by dissolving nitrocellulose in amyl acetate, wood alcohol, acetone, or a mixture of these.

Colored lacquers are produced by grinding colored pigments in plain lacquers, and transparent colored lacquers are made by adding soluble colored dyes to plain lacquer.

During recent years paints and varnishes have been greatly improved for drying, gloss, hardness and resistance to foreign substances due to the development and use of many types of synthetic resins, such

as phenolic—phenol formaldehyde, alkyds, oil, glycerine, phthalic anhydride, urea formaldehyde and others.

Paint, Varnish, and Stain Terms

acetic acid—A colorless, pungent, mobile liquid obtained by the distillation of wood.

acetone—A limpid chemical solvent.

amyl acetate—A chemical compound of acetic acid and alcohol.

aniline dyes—Liquid colors obtained by chemical means from coal tar.

anolyte—The portion of an electrolyte in the immediate vicinity of an anode.

benzene—A light, water-white distillate from coal tar.

bloom—A clouded appearance in a varnished surface.

buckle—Thin lead disk containing holes and used as the basic material for corroding into white lead.

carbonate of lead—White lead.

carbon dioxide—A gas composed of one part carbon and two parts oxygen.

catholyte—The portion of an electrolyte in the immediate vicinity of a cathode.

chlorine gas—An elementary gaseous substance obtained from salt.

chromium—A metallic element.

cobalt—A metallic element.

covering power—The extent of the spreading power, also hiding power, of a paint or varnish.

crazing—The formation of fine interlacing cracks in varnish.

denatured alcohol—Alcohol treated with some substance to render it unfit for beverages or medicine.

extenders—Pigments of cheaper materials, as chalk, whiting, and coal, used to increase the bulk of paint.

ilmenite—A mineral compound of iron oxide and titanium oxide from which titanium oxide paint is obtained.

flat paint—Any paint that does not dry with a glossy surface.

flouring—The gradual crumbling of a varnish into dust.

foots—Foots, in general, is the sediment in any oil.

fossil gum—Resins from certain trees that have been buried in the earth for centuries and become fossilized.

hiding power—The power of a paint to obscure a surface.

lakes—Colors formed by combining animal or vegetable matter or cobalt dyes with a metallic base.

linseed oil—Oil obtained from flaxseed.

livering—The coagulation of varnish, becoming liver-like.

opacity—The power to intercept rays of light.

pigment—Any dry, earthy, fine substance which, mixed with a vehicle, forms a paint.

stack house—The building in which the pots of lead buckles are placed for the corroding process.

tung oil—Oil obtained from the nuts of the tung tree.

varnish—A resinous solution of certain gums or resins in alcohol, linseed oil, or other liquid to produce a shiny, transparent surface.

vehicle—An oil or other liquid with which a pigment is mixed to produce a paint.

Paint Questions

Group I

1. In general, of what does a paint consist?

2. By what general process is white lead produced from metallic lead?

3. What is the source of the metallic lead used in the production of white lead?

4. Why are the corroding pots constructed with holes in their sides?

5. Why are the corroding pots constructed with a ledge?

6. How long does the corroding process require, and what general temperature is required? What causes the temperature to rise?

7. How does titanium oxide compare with white lead for paint?

8. What is the name of the mineral from which titanium oxide is obtained, and where are extensive deposits found?

9. What is meant by an earth pigment?

10. Name several of the more common earth pigments.

11. Name several oils used for paint vehicles, and give the source of each.

12. How are common bronzes made? How are they designated? Name some of their common uses.

13. What happens to the cake produced in making linseed oil?

Group II

14. Why must a paint pigment be very fine?

15. In the production of white lead why are the corroding pots made of clay instead of metal?

16. Why are the lead buckles constructed with holes in them?

17. Why should metallic lead for white lead be pure?

18. Explain why the inside of the bottom section of the corroding pot is glazed.

19. Why are earth pigments generally the cheapest?

20. What qualities should paint for outside work have that differ from the qualities desirable in paint used for inside work?

21. Why should paint for kitchens differ from that for bedrooms and living rooms?

22. What is the objection to using water as the vehicle for ordinary paint?

23. Why are extenders sometimes objectionable in paint?

24. In what respect does the production of zinc oxide resemble that of turpentine?

25. What is meant by water paint? For what is this generally used?

26. What is meant by the binder in water paint?

27. Explain the main difference between paint, varnish, stain, enamel, and lacquer.

28. What relation does the paint-and-varnish industry have to the wood-distillation industry?

29. What effect does the automobile industry have on the paint-and-varnish industry?

30. Explain what is meant by flat paint.

31. Efforts are being made to grow China-wood trees in this country. Explain the advantages of this move.

32. In what general respect should paint used for a steel bridge differ from that used for house work?

33. Why should workmen use breathing protectors when handling dry white lead?

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